DOCUMENT RESUME

ED 191 706 SE 031 925

TITLE	National Science Foundation Annual Report 1979.
INSTITUTION	National Science Foundation, Washington, D.C.
REPORT NO	NSF-80-1
PUB DATE	80
NOTE	147p.: Contains colored and shaded charts and photographs which may not reproduce well.
AVAILABLE FROM	Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402 (no price quoted).
EDRS PRICE	MF01/PC06 Plus Postage.
DESCRIPTORS	*Annual Reports: Budgets: *Federal Programs: Government Role: *Mathematics: Mathematics Education: Science Education: *Sciences: *Scientific Research: Teacher Education

ABSTRACT

Presented are highlights of research efforts supported by the National Science Foundation (NSF) in the areas of mathematical and physical sciences: astronomical, atmospheric, earth, and ocean sciences: biological, behavioral, and social sciences: science education: engineering and applied science: and scientific, technological, and international affairs for fiscal year 1979. Also included are Staff Advisory Committees and Panels, patents and inventions resulting from NSF supported activities, and the summary NSF financial report for fiscal year 1979. (CS)

****
* Reproductions supplied by EDRS are the best that can be made *
* from the original document. *
****

National Science Foundation
Annual Report 1979

ED191706

SE 031 925

U.S. DEPARTMENT OF HEALTH,
EDUCATION & WELFARE
NATIONAL INSTITUTE OF
EDUCATION

THIS DOCUMENT HAS BEEN REPRODUCED EXACTLY AS RECEIVED FROM THE PERSON OR ORGANIZATION ORIGINATING IT. POINTS OF VIEW OR OPINIONS STATED DO NOT NECESSARILY REPRESENT OFFICIAL NATIONAL INSTITUTE OF EDUCATION POSITION OR POLICY

Cover: The Very Large Array Radio Telescope near Socorro, New Mexico. (Page 27)

National Science Foundation

Twenty-Ninth Annual Report for Fiscal Year 1979

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402

AUG 18 1980

Letter of Transmittal

Washington, D.C.

DEAR MR. PRESIDENT:

I have the honor to transmit herewith the Annual Report for Fiscal Year 1979 of the National Science Foundation for submission to the Congress as required by the National Science Foundation Act of 1950.

Respectfully,

R. C. Atkinson

Richard C. Atkinson
Director, National Science Foundation

The Honorable
The President of the United States

Contents

Page

Director's Statement vii

Mathematical and Physical Sciences 1
  Physics 2
  Chemistry 5
  Mathematical Sciences 8
  Computer Science 11
  Materials Research 13

Astronomical, Atmospheric, Earth, and Ocean Sciences 19
  Astronomy 21
  Atmospheric Sciences 28
  Earth Sciences 36
  Ocean Sciences 41
  United States Antarctic Research 47
  Arctic Research 48

Biological, Behavioral, and Social Sciences 51
  Physiology, Cellular, and Molecular Biology 52
  Environmental Biology 56
  Behavioral and Neural Sciences 60
  Social and Economic Sciences 63

Science Education 67
  Science Education Resources Improvement 67
  Science Education Development and Research 72
  Scientific Personnel Improvement 75
  Science and Society 80

Engineering and Applied Science

  Electrical, Computer, and Systems Engineering 86
  Chemical and Process Engineering 89
  Civil and Mechanical Engineering 92
  Intergovernmental Science and Public Technology 93
  Applied Research 95
  Problem-Focused Research 97

Scientific, Technological, and International Affairs 103
  Policy Research and Analysis 104
  Science Resources Studies 105
  NSF Planning and Evaluation 108
  Information Science and Technology 109
  International Cooperative Scientific Activities 110

Appendices

A. National Science Board, NSF Staff, Advisory Committees and Panels 113
B. Patents and Inventions Resulting from Activities Supported by the National Science Foundation 133
C. Financial Report for Fiscal Year 1979 135
D. National Research Center Contractors 138

Heading for the 1980's

Nearly 30 years ago, writing in the initial *NSF Annual Report*, James B. Conant, the first Chairman of the National Science Board, set out some of the goals for a new and decidedly untraditional Government agency. "By and large," he observed, "the United States has not yet produced its share of such scientific pioneers as compared to Europe. One of the purposes of the National Science Foundation is surely to right this balance...".

That balance has long since been achieved and is now tipped in the United States' favor worldwide. In reviewing the contents of this last *NSF Annual Report* of the 1970's, I am struck, though not surprised, by the incredible diversity of achievement in research by U.S. scientists this past year. We are fortunate to have such momentum as the decade closes, because we face monumental technological challenges ahead—energy supplies, industrial and economic productivity, worldwide demand for food, environmental protection.

The value of a national capability in science that ranges from the kinds of basic research supported by NSF to the plainly practical applications of industry is the versatility and independence we are able to bring to problem-solving. Innovation without new knowledge soon runs dry, and our responsibility as a Nation is to make sure we keep this process working.

Some of the results reported in this volume already point towards their potential impacts outside the laboratory. A geophysical survey aimed at unraveling the ancient history of earth movements under the Appalachian Mountains has revealed an immense mass of hidden sedimentary rock. It certainly warrants further investigation as a possible source of oil and gas. An attempt to refine the taxonomic classifications of soil nematodes—a "flora and fauna" kind of study—has uncovered unusual modes of reproduction that appear to be important to controlling the substantial crop losses caused by these organisms.

Earlier research on the "shapes" of raindrops has now enabled another grantee to use radar to estimate directly the amount of rain falling during a storm—perhaps a method to get early warning of floods. Other scientists have found that measurements of changes in air pressures and winds may permit them to forecast, seasons in advance, global climate cycles and changes in commercially vital ocean upwelling patterns.

Engineers report several exciting advances with important potential. In another step towards eventual widespread use of optical waves for better communication systems, two researchers propose ways to remove distortions from transmitted signals. This expands the practical possibilities of using a transmission medium as accessible as the atmosphere itself. Another group has devised an environmental sensor built right into a transistor; this has far-reaching possibilities for self-contained microcontrol systems, and perhaps for biomedical uses as well.

Mechanical engineers have brought new light to some traditional research areas with important advances in the theory and practice of filtration—critical to a host of industrial and commercial processes—and in reducing aerodynamic drag under subsonic conditions—and possibly saving fuel for trucks and ships.

These are gratifying examples of the impacts of basic research. Indeed, it is always pleasing to see how some of the important questions in science parallel important societal concerns. However, by far the bulk of the research described here is important because of its relevance to basic scientific goals of understanding nature. Practical benefits will come later, if at all.

Among the far-reaching results this past year was early experimental evidence that a heavy quark "atom," whose existence is predicted by fundamental theory, may have been detected. If confirmed, this discovery, along with recent support for the existence of the "gluon" particle that holds quarks together, would give strong confirmation to the overall quark theory of matter.

In mathematics a classic theorem in geometry that has perplexed researchers for more than 150 years was finally solved. Interestingly, the solution included proof that part of the theorem, long suspected by most mathematicians to be true, was false—a reminder that rethinking old assumptions can sometimes be rewarding.

A number of astronomers, using different instruments at three National Observatory locations, have studied in great detail what appears to be a double quasar—a unique pairing of those mysterious objects. The possibility that we may be seeing a double image instead—caused by a supermassive black hole deflecting the light beam from a single quasar—is equally intriguing. In another study, astronomers also believe they finally have evidence that gravity waves—predicted by Einstein's General Theory of Relativity—do exist. This finding is sure to spur continuing experiments to detect the waves directly.

Widespread efforts to understand how the Earth's crust is formed and modified received assistance on several fronts. Deep-diving expeditions by the *Alvin* produced evidence for how magma beneath ocean spreading centers is emplaced as seafloor rock and how minerals are deposited from hot-water plumes from the ocean floor. Other scientists have devised new ways to determine the ages of sedimentary ocean rock and the history of the oceans above them, in one case using bits of skeletal debris from fish and microfossils, in another using traces of tiny organisms that bore into shells.

The reports from chemistry this year are a dramatic illustration of the powerful investigative techniques conferred by new research instrumentation, particularly those kinds built around lasers. Chemists can now follow the steps in ultrafast reactions, learning how molecular structure affects the exchange of energy and detecting intermediate reactants that exist for only a blink of time. Other techniques have made possible higher resolution, faster detection of incredibly small amounts of material; among the potential uses are studies of biomolecules such as peptides and nucleotides. So important have such instruments become to chemistry and allied sciences that NSF has established regional centers throughout the country where investigators may come to use these expensive and complex instruments to do research not possible at their home institutions. Fourteen such centers are now in operation.

In recent years the role of the membranes surrounding cells has attracted intensive study. Once thought of as little more than bags to enclose the cellular material, the membranes are now seen as the critical communications interface with the rest of the organism. Several studies reported this year concern how the membrane receives and transmits signals to the cell nucleus where the genes are located. Particular attention is being paid to binding of external material in receptors on the membrane, and to the actual manipulation and transport of certain substances into the cell itself. Another group of studies is looking at how some of those substances that do pass through membranes—hormones—actually interact with the genes to initiate the synthesis of specific proteins needed by the organism.

There are several additional things I would like to note in looking back on activities during the past year. An idea that had been discussed for many years in the education community finally saw fruition in a new Cabinet-level Department of Education. A few programs formerly administered by NSF, and which are more appropriately linked with Department of Education goals, have been transferred to that new agency. However, the balance of the NSF program— which is characterized by deep involvement in educational projects by the scientific research community itself—remains under the management of NSF. Among the major projects reported this year is the production of a new science television show, "3.2.1. Contact." This daily Public Broadcasting System program is aimed at 8- to 12-year-olds with the hope that more young people will remain receptive to science and mathematics and continue to study them in school.

In the area of policy research, NSF was heavily involved in support of the Domestic Policy Review on Industrial Innovation, and also produced the Domestic Policy Review on Non-Fuel Minerals. The Foundation continued its responsibility for preparation of the *Annual Science and Technology Report to the Congress*, and undertook production of the first *Five-Year Outlook for Science and Technology* for release in 1980.

The accomplishments reported in this publication are encouraging to those of us who look to advances in science and technology to fuel our Nation's progress through the 1980's. Indeed, among our resources, our lead in science and technology—if we will continue to nurture it—may be the most valuable we have.

Richard C. Atkinson
Director

Mathematical and Physical Sciences

1

Research in the Mathematical and Physical Sciences (MPS) ranges from theoretical studies to experiments, with the ultimate objective to understand the physical laws that govern the universe. In the MPS programs, basic research is supported across the disciplines of mathematics, computer science, physics, chemistry, and materials. The results of this research are useful to scientists within the specific disciplines and impacts, as well on other fields. For example, the recent development of instrumentation drawing on results of basic research in the rapidly changing fields of electronics, materials, and computer science has had a major impact on all scientific endeavors that use instruments as analytical tools.

The continued success of Americans in winning Nobel Prizes for past research, while not necessarily indicative of the current vitality of the Nation's scientific strength, is nonetheless an impressive achievement. The Foundation, in general, and its MPS programs, in particular, fared eminently well in 1979. NSF, as well as the National Institutes of Health, has supported Herbert C. Brown of Purdue University for many years. His research on boron chemistry earned for him a share of the Nobel Prize in Chemistry. Two theoretical physicists supported by NSF, Sheldon H. Glashow and Steven Weinberg of Harvard University, shared the 1979 Nobel Prize in Physics with Abdus Salam for their contributions to the theory of weak and electromagnetic interactions.

While there is no Nobel Prize in mathematics, comparable recognition of high achievement in mathematical research is attached to the Fields Medal. Starting in 1936, a maximum of four medals have been awarded at each quadrennial International Congress of Mathematicians, with the exception of the World War II period and in 1946. In 1978, in Helsinki, NSF grantees Daniel Quillen of the Massachusetts Institute of Technology and Charles Fefferman of Princeton University received Fields Medals for their research on algebraic K-theory and several-dimensional Fourier analysis, respectively. A Soviet and a French mathematician were the other two recipients. In addition to the Fields Medal, Fefferman received the first Waterman Award in 1976 from NSF.

The Foundation was not the source of support for the research of Allan Cormack of Tufts University, co-recipient of the 1979 Nobel Prize in Medicine for the development of the computer assisted tomography (CAT) scanner. However, it is notable that this chapter describes NSF-supported research in applied mathematics to permit the interpretation of three-dimensional information about organs, such as a beating heart, derived from the use of the CAT scanner—impressive testimony to the interdisciplinary nature of modern science.

The programs in the Mathematical and Physical Sciences operate primarily through the support of research projects. Most of the awards permit individuals or

Table 1
Mathematical and Physical Sciences
Fiscal Years 1977, 1978, and 1979

(Dollars in Millions)

	Fiscal Year 1977		Fiscal Year 1978		Fiscal Year 1979	
	Number of Awards	Amount	Number of Awards	Amount	Number of Awards	Amount
Chemistry	881	$ 40.23	914	$ 43.05	905	$ 45.63
Physics	372	53.99	349	59.86	349	61.99
Materials Research	657	52.58	708	59.92	710	63.50
Mathematical Sciences	833	20.06	842	21.41	885	22.93
Computer Sciences	250	15.79	265	16.63	263	17.58
Regional Instrumentation Facilities	—	—	6	3.01	11	5.00
Industry/University Cooperative Research	—	—	8	0.74	24	1.59
Two-year and Four-year College Instrumentation	—	—	—	—	44	0.61
Total	2,993	$182.65	3,092	$204.62	3,191	$218.83

SOURCE: Fiscal Years 1979, 1980, and 1981 Budgets to Congress—Justification of Estimates of Appropriations (Quantitative Program Data Tables).

small groups of faculty, together with their graduate students and postdoctoral associates, to carry out projects in their own laboratories. This type of operation forms the traditional mode of scientific research within the university.

However, the essential requirements of some disciplines (such as accelerators for high energy physics research) and the increasing cost, sophistication, and capabilities of modern research instrumentation demand unique arrangements for their most effective use. The traditional mode of research in some of these fields is that of user groups performing experiments away from their home institutions at centralized facilities.

NSF therefore supports a number of regional and national facilities, including the Synchrotron Radiation Facilities at Stanford and Wisconsin, the National Magnet Laboratory at the Massachusetts Institute of Technology, the National Center for Computation in Chemistry at the University of California, Berkeley, and the Cornell Electron Storage Ring, as well as university-based groups of users at these and other centralized facilities. In addition, NSF supports several regional instrumentation facilities at different university locations and 15 interdisciplinary Materials Research Laboratories. An Institute for Theoretical Physics at the University of California, Santa Barbara, is also being initiated as a 5-year experiment to foster cross-disciplinary theoretical physics research.

Unsolicited research proposals originate with scientists, located primarily at colleges, universities, and nonprofit organizations, who wish to answer specific scientific questions. Most proposals are submitted on behalf of these researchers by their institutions. Proposals are then evaluated by members of the "peer" community (experts drawn from academia, industry, and Government) who are capable of understanding the intent of the research and the significance of the possible results. The principal criteria for evaluation are the scientific merit of the research proposed and the capabilities of the investigators to carry out that research.

Physics

Physics, the study of the basic properties and interactions of matter and energy, is currently in a period of intellectual excitement comparable to the ferment in the early 20th century. At that time, new theories of relativity and quantum mechanics revolutionized our concepts of space and time, of cause and effect, of certainty and uncertainty. Today's excitement centers around possibilities for:

- The unification of descriptions for the four known forces (strong, weak, electromagnetic, and gravitational) into a single theory.
- Detecting gravitational radiation from distant events in the cosmos.
- Unraveling the forces and particles binding matter into nuclei.
- Exploring the behavior of individual particles—e.g., single electrons trapped in special containers.
- Attaining unprecedented energy, temperature, density, and precision in all types of experimental studies.

This new excitement was brought about by a combination of intellectual propositions, such as the theory that matter is composed of quarks, and technological developments, such as colliding beam accelerators and lasers, which together provide the mutual challenges to theory and to experiment necessary to attract the attention of creative scientists. Two theoretical physicists supported by NSF, Sheldon H. Glashow and Steven Weinberg at Harvard University, shared the 1979 Nobel Prize in Physics with Abdus Salam at Imperial College of London for their contributions to the theory of weak and electromagnetic interactions.

NSF's physics program supports experimental and theoretical investigations into elementary particle physics, nuclear science, atomic and molecular physics, plasma physics, and gravitational physics. Experimental research is carried out using a variety of facilities and instrumentation covering a range of scale: major, centralized, charged particle accelerators like those at Cornell and at the national laboratories supported by the Department of Energy, large in-house pieces of instrumentation like tandem Van de Graaff accelerators and cryogenic bar gravitational wave detectors, and tabletop laser arrays and minicomputers. Theorists provide the intellectual framework within which the experimental results are interpreted, based on a combination of physical and mathematical models.

These programs provide about one-half of the total Federal support for university-based physics research. This support is vital in assuring a strong national program of research in all areas of physics. The types of activities supported include: major instrumentation development and upgrading, major national user facilities, in-house university laboratories, groups of users of centralized facilities, research institutes, laboratory-scale experiments, and theoretical studies. Some specific examples of such projects supported in 1979 are:

- The Cornell Electron Storage Ring, an accelerator for elementary particle physics experiments, recently converted to a positron-electron colliding beam facility from its former operation as a synchrotron.
- Cyclotrons for nuclear science research at four universities.
- Tandem Van de Graaff accelerators for nuclear physics research at nine universities.
- Superconducting electron accelerators under development at Stanford and Illinois.
- An Institute for Theoretical Physics at the University of California,

Santa Barbara, which is a 5-year experiment to encourage cross-disciplinary theoretical physics research.

- A variety of university groups using Department of Energy- or NSF-supported centralized facilities for particle, nuclear, and plasma physics.
- Experimentalists and theoreticians working on physics problems at their home institutions.

Some of the recent results of a few projects are described on the following pages.

Solutions of Einstein's Equations

One solution of the Einstein equations, considered the key general relativity equations, describes the structure of space and time in the strong gravitational field of a stationary massive object. But astrophysicists have a particular need for so-called stationary solutions in which the massive object is also *rotating*. These would be useful in the study of collapsed stars and the physical processes that may go on about them. Einstein's equations are nonlinear and difficult to solve, however, and few exact solutions of this type have been found.

The solutions corresponding to *nonrotating* objects were found by Hermann Weyl in 1917, in the very early days of general relativity. But until 1976 only two or three solutions for rotating objects were known, and ways to develop systematic methods for producing realistic stationary solutions for many different cases were clearly needed. It would appear that this longstanding problem has now been completely solved as a result of the efforts of William Kinnersley at Montana State University and his collaborators.

The general approach used has been *solution generation*. First, one must discover some symmetry property of the Einstein equations. This is interpreted as a *transformation* and may be applied to any known solution to generate a new one. In this way the labor of actually solving the equations is avoided. A few such transformations were found by Jürgen Ehlers at the University of Texas and B. Kent Harrison at Brigham Young University in the 1960's, but the solutions they generated were unrealistic for astronomical purposes. Kinnersley's research, begun in 1976, tried to identify all of the symmetry properties of the stationary Einstein equations so that all possible solution-generating transformations could be written down. This permitted the identification of those that led to realistic solutions.

His first breakthrough came with the discovery that every Einstein solution carries with it an infinite set of "potentials." These are mathematical quantities that express properties of the gravitational field and are a unique consequence of the Einstein equations. He expressed the existing Ehlers-Harrison transformations in a new notation and saw that they involved the first few potentials. This suggested a way to write more general transformations that would make use of the higher potentials in an analogous way. Kinnersley was able to verify that these new transformations did, in fact, correspond to new symmetries of the Einstein equations.

Kinnersley believes that these transformations constitute an essentially complete solution for the gravitational field of a uniformly rotating body. The calculations require only algebra and are straightforward enough to be programmed on a computer. Thus nonspecialists may use this method to construct their own solutions meeting particular requirements. This gives astrophysicists a wealth of realistic gravitational fields to use in their models of collapsed objects. It represents the widest class of solutions of the Einstein equations ever found.

Giant Atoms

Atoms prepared in highly excited states (Rydberg atoms) by the new narrowband tunable lasers have unusual properties brought about by the fact that the atom's outermost electron is thousands or tens of thousands of times more distant from the atomic nucleus than in the usual atomic systems. Interactions of such large atoms with other particles and photons have occupied the interest of several research groups supported by NSF. Recently, these groups obtained results that may have important implications in fundamental atomic studies (such as an evaluation of relativistic effects in atomic hydrogen) as well as in such applications as radioastronomy studies and ionization and recombination in gaseous nebulae.

In the interaction of these Rydberg atoms with particles, Keith MacAdam at the University of Kentucky found enormous effective diameters (comparable in size to an amoeba) for collisions between helium ions and some Rydberg atoms of sodium. This is an example of the extreme properties exhibited by these systems. Peter Koch at Yale, meanwhile, found that the Rydberg electron bound to a fast atom scatters from neutral particles almost as if it were free, while the nucleus acts as a "distant spectator."

Thus, results from experiments with the Rydberg atoms can be analyzed as though performed with free electrons. Koch's observations provide the first experimental verification of theoretical predictions made for collisions of fast Rydberg atoms.

Especially exciting results have been reported by the Rice group of Ronald Stebbings and F. Barry Dunning and the research group of Thomas Gallagher and William Cooke at SRI International for photon interactions with Rydberg atoms. Again, the extreme behavior of these Rydberg systems enables them to interact strongly with far-infrared or microwave radiation.

Both groups have observed unexpected dramatic effects in Rydberg atoms caused by room-temperature blackbody radiation. In more conventional atomic systems this background radiation is something that can be completely ignored. But the SRI group has observed that this blackbody radiation can induce the action of a maser when it triggers the Rydberg atoms to coherently emit microwave radiation. These blackbody effects have important implications for atomic frequency standards and also illustrate the potential of these systems as sensitive, efficient detectors of far-infrared radiation.

Taking the Temperature of a Plasma

A group from the University of Maryland, headed by Derek Boyd and Chuan Liu, has been studying the properties of an unusual sort of plasma—one consisting principally of energetic electrons confined in a magnetic field. Such electrons emit synchrotron radiation, which in this case lies principally at wavelengths between the microwave and the infrared.

This radiation carries information about the velocity distribution of the electrons and, if its characteristics can be measured accurately, represents a key, nonperturbing way of studying the plasma and comparing its actual properties with those predicted theoretically. The Maryland group developed a new apparatus for measuring the temperature and other characteristics of this radiation at a number of wavelengths, using cryogenic detectors that would respond quickly to changes in the plasma. Excellent agreement was found with the predictions of the theory of non-neutral plasmas, which was developed in parallel by them.

In order to study the properties of a different sort of plasma the Maryland group moved its measuring system to Princeton to make use of a facility supported there by the U.S. Department of Energy's fusion program. The Maryland "user" group was then able to study the properties of the plasma confined in the Princeton Large Tokamak and make new measurements on the velocity of fast electrons moving parallel to the confining magnetic field. Again, good agreement was obtained between the experiment and theoretical predictions of the radiation expected from such a plasma.

A key problem in the fusion energy program, whose goal is to develop a practical thermonuclear power source, is measuring the temperature in the plasma within which the nuclear fusion reactions between light nuclei take place. This plasma, such as that within a tokamak device, must be at approximately 100,000,000°C for fusion reactions to happen spontaneously. This thermal energy must be shared among all the particles, not carried by only a few fast electrons that would not interact with the main body of the plasma. The new method for measuring the synchrotron radiation proved to be capable of showing that all the electrons were being heated and, in turn, were heating the nuclei with the hoped-for efficiency.

The results of these measurements thus proved to have both fundamental interest to plasma physics and, at the same time, provided the fusion program with an unexpected and important new diagnostic technique for studying and monitoring a plasma in tokamaks. The Department of Energy has since initiated the construction of new measuring systems based on the experience of the Maryland group and will install them on several of the largest tokamaks as routine diagnostics. The original basic physics study thus had an immediate if unplanned application, which was found because of the close collaboration between the scientists and the agencies involved.

States of the Charmonium Atom

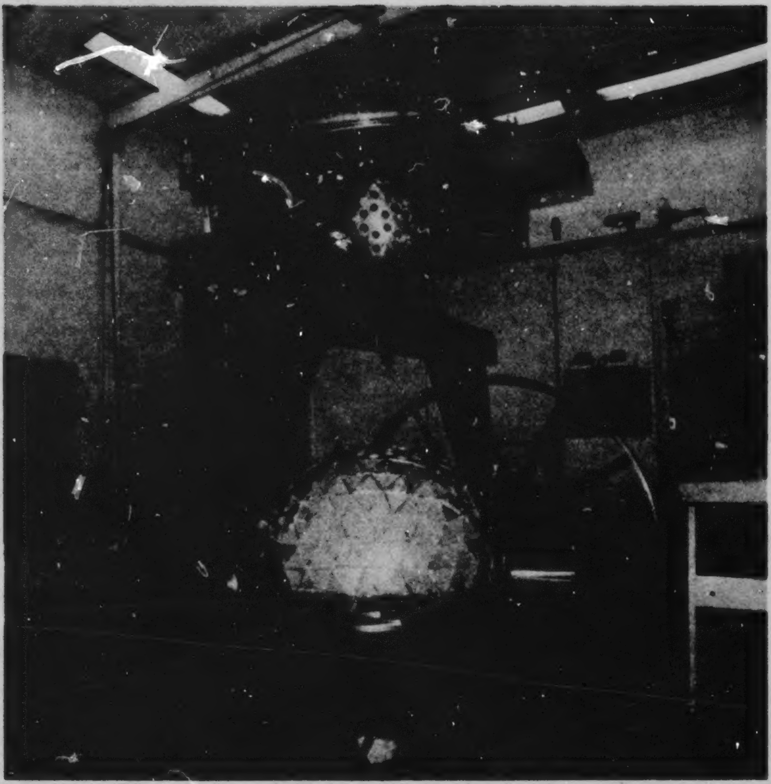
The J/psi particle discovered in 1974, by two groups whose leaders shared the Nobel Prize for the discovery, is believed to be a simple analog of an atom composed of a charmed quark bound to a charmed antiquark (charmonium atom). The binding force, or glue, that holds the quark and antiquark together is thought to consist of a cloud of elusive particles termed "gluons." These gluons are, physicists believe, the ultimate source of the binding force that holds all atomic nuclei, and all the strongly interacting subnuclear elementary particles, together. Intriguing evidence that the gluon does indeed exist has recently been found at the new high-energy electron-positron storage ring in West Germany, and has received wide publicity.

Several theoretical physics groups, including especially NSF-supported ones at Cornell and at Harvard, have predicted that if J/psi is indeed a quark and an antiquark bound by forces carried by gluons, then there should be other, more massive, J/psi-like states. These states are actually different configurations of the quark and the antiquark, having higher energy and thus more mass. Any one of them can turn into one of the lighter states by transforming the excess mass into electromagnetic energy, carried off by a photon. A number of the properties of these states, such as their masses and the rates at which the heavier ones make electromagnetic transitions to lighter ones, are predicted by theory.

Although five of the states of charmonium atom had been discovered with first-generation detectors, and had been found to have the predicted characteristics, evidence for the remaining two predicted particles was very scanty. In fact, there were reports of states that had incorrect masses by comparison to theory and that also had electromagnetic transition rates in strong conflict with predictions.

This contradiction has been removed by experiments using a new, second-generation detector, called the Crystal Ball, which recently came into operation. This is an array of sodium iodide crystals arranged in a configuration that almost completely surrounds the interaction region, detecting energetic photons emitted by particles in process of changing from one state to another. The crystals convert the photons, emitted as high energy gamma rays, into visible light which is then detected with a photomultiplier. Experiments at the Stanford Linear Accelerator Center on the decay of the J/psi states showed that no states exist with the features that contradict theory. Several NSF-supported groups participated in building the Crystal Ball and in doing the experiments.

Experimenters have gone on to search again for the two predicted states. At a recent international conference at Fermi National Accelerator Laboratory, Elliot Bloom of SLAC reported preliminary evidence for one of them. The experimenters cautiously named this particle "U," for



Crystal ball. This highly sensitive photon detector, made from sodium iodide crystals for use at the Stanford Linear Accelerator, is part of the continuing search for predicted "charmed" quarks. Success in those experiments would be strongly supportive of the current quark theory of the composition of matter.

"unknown." This U particle has a mass within the range predicted for one of the two anticipated quark-antiquark states by theory; it is widely hoped that the U is further confirmed and is the long sought-after state. Efforts by the experimenters to confirm the existence of U and measure its properties are underway. Quantitative agreement between experiment and theory for the particles related to the J/psi would be a very important confirmation of the picture according to which matter is made of quarks bound together by gluons.

Chemistry

Chemistry plays a central role in our Nation's basic research enterprise and, consequently, in our economic well-being. The chemical industry alone is responsible for 6 to 7 percent of the Gross National Product, while food (10 percent) and energy (20 percent) are affected strongly by chemical research. Antibiotics, many of them first isolated, chemically characterized, and synthesized in university chemistry laboratories, have greatly reduced the death rate from infectious diseases in developed countries.

Chemical research has become more sophisticated than it was only a few years ago as chemists unravel the secrets of atoms and molecules at the most fundamental level. Sophistication arises from the availability of an entire new range of measuring capabilities. The laser, the synchrotron, superconducting magnets, and the minicomputer are each permitting the study of chemical phenomena in highly controlled environments where measurements on tiny amounts of matter can be made with great precision. Chemists challenge the future with this ability to prove and understand previously unexplored regions of nature, and they transfer this new knowledge to allied fields in medicine, agriculture, environment, and industry of all types.

Chemistry has always been concerned with the synthesis, isolation, and characterization of new and naturally occurring compounds. Organometallic chemistry has emerged as an important subdiscipline that promises to provide a systematic approach to the preparation of new molecules, many of which show promise as catalysts. The Nation's chemical industry is heavily dependent on catalytic processes, and they are vital to many new energy production techniques. Thus, basic research in understanding catalysis has great potential for creating new products of great value and conserving energy.

New sensors, detectors, and methods of data acquisition and control have changed the way chemists review research opportunities. As an example, it is now possible to probe with lasers the energy distribution in molecules during chemical reactions and even to select particular reactants for study on the basis of their energy content. Similarly, as a result of advances in computer technology, a highly tractable theoretical and computational framework is available to guide experimentalists in the selection and interpretation of important experiments and to provide a sound basis for formulating new chemical principles.

The four topics discussed below provide further illustration of some of these ideas and suggest ways that the results may contribute either directly, or through allied fields, to the benefit of mankind.

Picosecond Studies of Ultrafast Molecular Processes

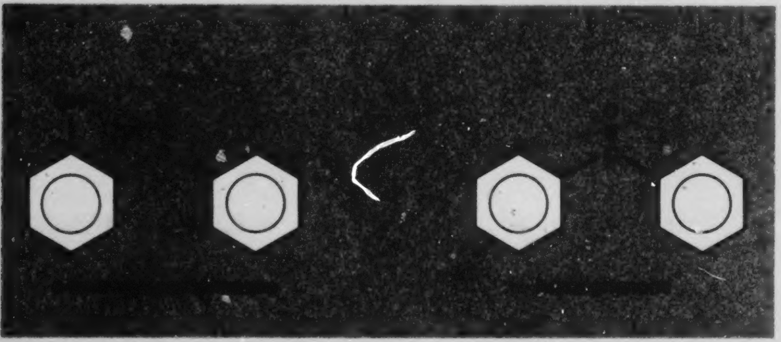
The motion of atoms and molecules, the transfer of energy between molecules, the breaking of a chemical bond, or the hopping of an electron or proton from one molecule to another are events that have one common element. Each of them can, and often does, take place in a matter of a trillionth of a second, called a picosecond. In this short interval a photon travels only 0.3 millimeter. In order to understand the motion of electrons and atoms in molecules, chemists must perform experiments within this time frame.

The exploration of rapid, light-induced processes has undergone a revolutionary advance with the availability of lasers that can generate light pulses of picosecond duration at power levels of ten trillion watts. Several NSF-supported research groups are applying picosecond laser methods to the study of ultrafast processes.

One group is led by Kenneth B. Eisenthal at Columbia University. Eisenthal's work focuses on the role of hydrogen, either as a proton or as an atom, in determining the structures and reactivity of chemical species. A dramatic example of the role of hydrogen is seen in a comparison of the photochemical stability of a compound to which only a hydroxyl group (oxygen and hydrogen) is added. The parent compound (benzophenone, in the experiment) is highly photoreactive. The hydroxyl-enriched compound (*o*-hydroxybenzophenone), however, is so stable as to be used as a protective agent against light-induced decomposition in polymer systems.

Employing picosecond laser techniques, Eisenthal and his coworkers have established how the enriched compound functions as a protective agent. At the molecular level, the hydrogen (bound between two oxygen atoms) shortens the lifetime of the excited state of the molecule, causing it to lose its energy before it can react with other species. Thus, the highly reactive excited state form is rapidly returned to an unreactive ground state.

Hydrogen also plays a major role in another interesting and rather unusual system (the dimer of 7-azaindole, whose structure is stabilized by hydrogen bonds). Upon absorption of a photon the hydrogen bonds shift simultaneously to produce a different structural form, the *tautomer*. Eisenthal's group has found that the double proton transfer is very rapid, occurring in less than 5 picoseconds. This system has generated widespread theoretical and experimental interest, not only because it involves excited-state proton transfer, but also because the dimer of 7-azaindole is similar to the hydrogen-bonded base pairs of DNA. This system is being investigated as a model for light-induced genetic changes.



Role of hydrogen. The difference between the compound benzophenone, which reacts strongly with light, and o-hydroxybenzophenone, which is unreactive with light, is the presence of a hydroxyl group (OH). Ultrafast laser techniques have enabled chemists to understand why the OH group changes the reactivity of the compound.

Chasing "Free Radicals" with Lasers

In the course of the combustion of hydrocarbons, a variety of highly reactive intermediates called free radicals are produced. Monitoring these intermediates is the key to obtaining a basic understanding because they play an important role in determining the rate of the process and the final products. Methods for detecting free radicals and following their pathways have been the subject of intensive efforts for many years. Because the chemical reactivity of free radicals causes them to be destroyed very quickly, no completely satisfactory means of studying them has been developed until the advent of lasers.

The recent development of a variety of lasers suitable as light sources for spectroscopy has provided a powerful means of detecting free radicals. Spectroscopy is the science of characterizing molecules by the nature of the radiation that they absorb or emit. Conventional radiation sources such as light bulbs produce light which has a wide range of wavelengths, while lasers are an extremely intense source of radiation concentrated at a single wavelength. It is this brilliance and monochromatic character that makes the laser a much better source of light for spectroscopy than any previously available.

Many scientists utilize lasers and several groups are studying free radicals. One such program, jointly directed by chemist Robert F. Curl and electrical engineer Frank K. Tittel at Rice University, uses a variety of laser sources. The structures of several free radicals have been studied using a continuous wave (CW) dye laser, which excites the free radical and causes it to give off light, i.e., fluoresce. A special technique called microwave optical double resonance (MODR) has been employed to greatly improve resolution and provide a detailed description of the radical NH_2, which is thought to be a relatively abundant constituent of interstellar space. The microwave transition frequencies obtained in this study have stimulated the search by radioastronomers for this molecule, which so far has eluded detection.

Fluorescence provides a sensitive and powerful method of studying free radicals. However, there are many systems that cannot be studied by this technique because the free radical does not absorb visible light. On the other hand, almost all molecules absorb infrared radiation, and this allows their detection and measurement. Until recently infrared laser spectroscopy has been difficult because the infrared lasers available have not been tunable, have been very difficult to use, or have had a very low output power.

This situation has changed with the development of the color center laser. This laser promises to be an extremely versatile radiation source for infrared spectroscopy and will provide a means of studying a wide variety of free radicals. A computer-controlled color center laser suitable for the study of free radicals has been developed and tested by obtaining spectra of stable molecules. Studies of free radicals thought to be important in combustion are now in progress.

Mass Spectrometry on Microquantities

Instrumentation for chemical measurements has closely followed the rapidly changing fields of electronics and computers. One of the most significant developments has been the adaptation of Fourier transform (FT) methods to nuclear magnetic resonance (NMR) and infrared (IR) spectroscopy. The FT techniques have resulted in vastly increased sensitivity and speed by simultaneous detection of all signals. The FT methods have allowed the acquisition of NMR and IR spectra on samples consisting of less than a millionth of a gram.

Mass spectrometry (MS) at first glance appeared to be a technique to which FT methods were not applicable until Melvin B. Comisarow and Alan G. Marshall at the University of British Columbia demonstrated FT ion cyclotron resonance (ICR). Before that ICR mass spectrometry had been useful for the study of gas phase reactions of ions but was of limited sensitivity and resolution. With the promise of increased sensitivity and resolution it was clear that FT-MS had great potential as a new measurement technique in chemistry.

In conventional ICR mass spectrometry the ions are collected by changing the radio frequency (RF) or the magnetic field. In FT-MS all of the ions are irradiated at the same time and time-dependent behavior of the excited ions is observed. A decay to thermal energies occurs that is exactly analogous to relaxation in NMR spectroscopy. Additionally, if a delay of several hundred milliseconds is introduced after generation of the ions and before measurement, a totally different spectrum will result. These differences can be used to characterize very large or unstable molecules.

The major advantages of FT-MS are speed and resolution. Charles L. Wilkins and Michael L. Gross at the University of Nebraska have used a variable RF pulse to achieve very high resolution for fragmentation maps, and can even separate helium-3 and tritium on the basis of mass alone.

FT-MS appears to be particularly well adapted to nonvolatile molecules such as peptides and nucleotides. Robert T. McIver at the University of California, Irvine, has shown that 50 billionths of a gram of morphine are readily detectable, while Wilkins and Gross have found that

Measurements of microquantities. University of Nebraska chemists Charles Wilkins and Michael Gross (standing) and graduate student Sahba Ghaderi (seated) are among several university groups using new Fourier transform mass spectrometry techniques to achieve fast, high-resolution identification of species present in chemical processes.

100 billionths of a gram of cyclohexene can give useful spectra. The mass range observable by FT-MS is continuously being improved.

The speed, the sensitivity and the resolution achievable by FT-MS clearly show that the technique will have a major impact on chemistry and other related areas that use mass spectrometry in their arsenal of experimental tools. Further developments are projected using better cells, superconducting magnets and more powerful computers for better research tools. Fourier transform mass spectroscopy may revolutionize mass measurements in the same way that the Fourier transform technique has revolutionized NMR and IR spectroscopy.

Energy Scrambling on Surfaces

Chemical processes that occur at surfaces are of fundamental scientific interest as well as of great practical importance. In the past decade there has been much progress in this area due to the availability of new experimental techniques that can be used to gain insight into reactive processes on an atomic level. An understanding of reaction dynamics at surfaces and interfaces is essential for a molecular description of a number of technologically important processes, such as heterogeneous catalysis, oxidation, corrosion, and semiconductor device passivation.

Considerable information is available concerning the dynamics of chemical reactions occurring in the gas phase, including how fast such reactions occur and the way energy is distributed during the course of the reaction. This information has enabled chemists to propose simple rules for gas phase reaction mechanisms and rates and to predict these properties for reactions that have not been studied. The analogous situation does not prevail for heterogeneous (gas-solid) reactions. Only recently have techniques become available that allow detailed characterization of solid surface properties at a level even close to that gained from spectroscopic investigations for gas phase molecules.

One particular problem in heterogeneous reaction dynamics that has stimulated the interest of chemists recently is the question of energy disposition in heat-evolving (exothermic) surface reactions. For an exothermic reaction occurring on a surface, it is important to determine if all of the energy liberated by the reaction remains with the solid surface or if some of the energy is taken away from the surface as the product molecules depart.

Chemist Steven Bernasek and his colleagues at Princeton University are studying this problem. They have selected for study the recombination of nitrogen or hydrogen atoms on various transition metal surfaces. Using a technique known as electron beam-induced fluorescence, they measure the rotational and vibrational temperatures of nitrogen and hydrogen molecules desorbing from the metal surface following atom recombination on the surface.

The rotational and vibrational temperatures provide a measure of how much energy is available in the corresponding energy modes. Initial results indicate that when nitrogen atoms recombine on an iron surface, the desorbing molecules are somewhat "hotter," both rotationally and vibrationally, than the surface from which they come. This verifies that a significant fraction of the recombination energy remains with the recombined molecules as internal energy.

This is especially interesting in light of the observation by astrophysicists of rotationally excited hydrogen in interstellar dust clouds. One postulated mechanism for the source of this rotationally hot hydrogen is the combination of hydrogen atoms on dust grains, with molecular hydrogen desorption occurring before its internal energy is equilibrated with the solid surface.

Information of this type is also helpful in understanding the mechanism of catalyst sintering that can occur when a large amount of energy from an exothermic reaction is deposited in a small metal crystallite in a supported catalyst. This may cause the crystallite to coalesce with another crystallite in the vicinity, thus reducing catalytic activity by reducing the available surface area for reaction.

Experimental measurements of the internal energy of heterogeneous reaction products, when coupled with developing theories of gas-solid energy transfer, will provide a basis for the detailed understanding of the dynamics of heterogeneous reactions. This will allow the design of more efficient catalysts and the control of corrosion, oxidation, and other surface reactions.

Mathematical Sciences

The term mathematical sciences, as used in connection with NSF programs, comprises pure mathematics, statistics, and mathematics used in other scientific disciplines in an essential way. Pure mathematics refers to structures of symbolic reasoning which are studied with direct regard to their intellectual interest; this interest frequently arises through their being a highly abstract, but conceptually simplified, representation of the real physical world. Applied mathematics refers to the utilization and further development of these structures as a tool of research in other fields of science.

The distinction between applied and pure mathematics is not so much in subject matter as in motivation. For example, conic sections, group theory, invariants of linear transformations, and a host of other topics, first studied for their intrinsic interest, were later found to have fruitful applications to the study of the physical world. However, many mathematicians are initially motivated by the evident relevance of the things they investigate, and such mathematics ranges from differential equations of fluid flow to the design of error-correction codes.

Statistics as well as the probability

theory that underlies it, is obviously also a kind of applied mathematics, but it is such a distinct field that it is almost always described separately. All experimental work depends for interpretation on statistical analysis. This may be quite elaborate, particularly in medical experiments, where, for humanitarian reasons, some variables cannot be manipulated in the way optimum experimental design would dictate.

The heated pace of research in all major fields of the mathematical sciences makes it difficult to say with any certainty that there is an area in which future progress will be notably greater than in others. Development has been so widely distributed over mathematical fields that no one major area seems to remain long dominant in research produced. Nevertheless, among specific areas in which heightened activity may be expected, the following will perhaps be the most active or most rapidly growing in core mathematics during the next few years: partial differential equations, description of the structure of the three- and four-dimensional manifolds, operator algebras, classification of finite simple groups, algebraic geometry, and combinatorics with use of the computer. In applications, it is expected that continued great activity will occur in nonlinear wave theory, bifurcation theory, and robust statistical estimation.

Not unrelated to the rather even advance on many research fronts in mathematics is the growing symbiotic nature of its parts. One of the great, perhaps the greatest, themes of contemporary mathematics is synthesis: Insights from harmonic analysis turn out to be useful in combinatorics; methods from topology are needed in solving problems in differential equations; number theory requires methods from analysis and topology; probabilistic techniques are used to demonstrate new results in the geometry of Banach spaces; and algebraic methods become indispensable in the study of geometry and topology. There can be no doubt that this great movement will continue.

A second major theme now emerging, which seems destined in the course of time to be one of the major developments in mathematics, is the use of computers in mathematical research. Computers serve as tools for testing conjectures, suggest mathematical problems, permit numerical solution of many problems with arbitrary accuracy, and have highlighted the concept of algorithm in the solution of problems.

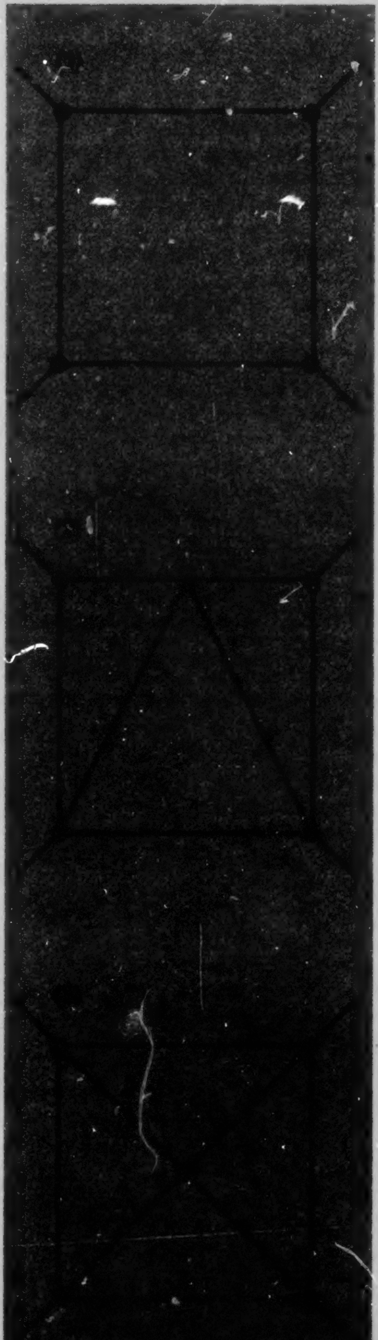
Rigidity of Frameworks and Structures

A geodesic (or geodetic) structure, according to Webster, is "domed or vaulted with a framework of light, straight-sided polygons in tension." But are all such structures provably rigid, regardless of the shape of the polygons? And can concave polyhedral structures be considered to be as rigid as convex?

This is a modern reference to a mathematical problem of very long standing that has just been solved. That long-standing problems meet with ultimate solutions is not surprising. Several years ago, the ancient four-color map problem finally was solved. But it required massive computations and was simply awaiting a computer powerful enough to handle them.

But within the past year, a proof was published of a geometric problem of comparable age and intractability, and this proof is of the traditional, pencil-and-paper variety, involving no machine computing.

The problem, first raised by the famous French mathematician A. L. Cauchy and



Cauchy's polyhedra. After more than 150 years, a mathematical proof has shown that the skeleton of any convex polyhedron (a three-dimensional figure with plane faces) composed of triangles is rigid. Proof that this is true in restricted cases (with faces composed as in (1) and (2)) was given 20 years ago. The proof for any such convex solid (which can have a face as in (3)), of fundamental mathematical interest, may also prove useful in structural design.

partially solved by him in a paper published in 1813, is to determine whether any convex polyhedral framework—comprising polygons joined at their edges—is rigid as long as the polygonal faces are made up of triangles.

Cauchy showed this to be so if each of the triangles represents a separate face of the solid. But he could not deal with the limiting case, for instance, of two triangles sharing a face of the polyhedron, the face of which, then, might be a square—two triangles joined at a common edge in the same plane.

Essentially, no progress was made for a century, until 1916, when Max Dehn improved somewhat upon Cauchy's result. Then, in 1958, A. D. Alexandrov proved a sharpened version of Dehn's theorem, concluding rigidity in the case of Cauchy's plane surfaces comprising triangles of a number of configurations, including even triangles in the surface that meet only at a vertex, so that their edges form one straight line segment.

This extended Cauchy's theorem, but still did not cover all cases of polyhedrons, the faces of which might be divided into other triangular arrangements—not, for instance, if vertices of the triangles are allowed to meet in the interior of a flat square face. And there the matter rested for another 20 years, until in 1978 Robert Connelly at Cornell University proved, without restriction, that any convex polyhedron whose faces are divided into triangles is necessarily rigid.

Two further comments are in order:

First, Connelly's proof of this theorem would have been understandable to Cauchy, despite all the mathematics of various kinds that has been developed in the intervening century and a half. Second, all the years that mathematicians wrestled with this problem, it was conceivable, and in fact widely suspected, that the convexity of Cauchy's polyhedron was a red herring—that actually any connected polyhedron, convex or concave, with triangles for faces, was rigid.

However, Connelly has also shown that this more general conjecture is false. In fact, one of his graduate students has constructed a cardboard model of a counterexample. It has triangular faces, it flexes slightly, and it can be proved that this is real flexing and not a result of the flimsiness of the cardboard. (Of course the model is not convex; some edges of its triangular faces project in, toward the figure's interior.) This last result could conceivably be of practical value if it forestalled the collapse of some unusual modern roof having a non-convex, polyhedral skeleton.

Robust Statistical Estimation

Theoretical and applied statisticians have merged their efforts in recent years to develop new kinds of statistical estimators called robust estimators. The basic idea is to try to buy insurance against having chosen a model that does not quite fit the real experimental situation, even at a possible cost of expending a small amount of the information in the data collected.

The traditional statistical estimation process begins by describing a probability model for a real-world situation about which a key aspect is unknown. The model involves an unspecified numerical parameter that corresponds to the unknown aspect. Experimental data are obtained, viewed as having come from the probability model, and used to compute an estimate of the parameter. A formula or algorithm with data as input and the estimate as output is called an estimator.

In situations of practical importance, many estimators are possible. It is a matter of both practical and theoretical importance to develop sensible criteria for making choices among estimators and to find, in each experimental circumstance, the estimator that is best according to these criteria.

One example familiar to most scientists is that of estimating the center of a Gaussian (normal) model from randomly selected observations (data). According to generally accepted criteria, the sample mean, or the average of the observations, is the best estimator for the Gaussian model. Another possible estimation is the sample median (the middle of the observations when ranked in order of size), but it uses the information contained in data from a Gaussian distribution slightly less efficiently than does the mean.

In practice, the weak link in the chain of reasoning leading to the estimation is that the mathematical model seldom fits the real-world situation exactly. As a consequence, no matter how carefully the optimality criteria are formulated, the results obtained from the estimation process may be misleading.

During the past few years the idea of robust estimators has been developed to try to offer some built-in insurance against certain kinds of discrepancies between the model and the real world. Central to this concept is the careful construction of a "supermodel" which contains not only the model thought to be correct, but also some other possible models. Then an optimal estimator, called robust, is sought within the broader context of the supermodel. The estimator so obtained is compared with the one that is optimal for the basic model. The hope, of course, is that the robust estimator will be almost as good as the other one, even if the basic model is just right, and will be better if the model is slightly wrong in one of the ways anticipated in the supermodel.

Sometimes the robust approach gives estimators that have been familiar to statisticians for years, and sometimes it gives estimators that have unfamiliar forms. The median is a familiar robust estimator. If Gaussian data may be contaminated in certain ways with "outliers" (grossly high or low readings), the median may be a safer estimator of the Gaussian center than the mean. As most researchers know, the mean is very sensitive to outliers. The slightly less efficient median is robust in some such cases.

In developing a general theory of robustness, a crucial issue is how to construct useful supermodels. Take too many possible departures from the basic model into account and the parameter of interest may not be meaningful any more. Too narrow a supermodel may not encompass the real experimental situation.

One common way (in estimating location parameters) of making sure that the meaning of the parameter is not "diluted out" in the supermodel is to specify the supermodel in terms of perturbations of the basic model and to insist that positive and negative perturbations of the same size be equally likely.

A number of the most creative theoretical statisticians have recently turned their attention to various other approaches, giving careful attention to applied needs, to obtain results that are realistic in a wider range of circumstances. They have had some important successes, and there is hope of obtaining unifying theories for making useful supermodels. This effort draws on results from several other branches of mathematics such as analysis, topology, and abstract algebra.

One especially promising approach, advocated and developed by Peter Bickel at the University of California, Berkeley, is to let the perturbations be lopsided, but to insist that their overall size be subject to certain probabilistic restrictions just stringent enough to ensure that the parameters of the original model remain meaningful.

Computed Tomography

Until relatively recently there was little need for a mathematical theory of radiology: Films were analyzed individually and by eye, and mathematics had little to offer to this procedure. The breakthrough called *computed tomography* radically changed this situation. In this process, attenuation of X-ray beams is measured in an extremely sensitive quantitative manner, and the information from X-rays from many different sources is assembled and analyzed on a digital computer.

In this new situation, mathematics can make significant contributions concerning the nature of the total information conveyed by X-rays from many sources, the extent to which this information determines the object X-rayed, suitable configuration of sources, and methods for using the data to build a detailed reconstruction of the object.

In the initial device used for computed tomography, the EMI scanner, a parallel X-ray beam was used, and two-dimensional cross sections of the object were reconstructed. The development of a mathematical theory appropriate to the abstract description of this device was supported during the period 1972-75 by NSF through a grant to K. T. Smith at Oregon State University. By 1975 the basic mathematical questions were settled; research emphasis then became of a clinical nature and was sponsored by the National Institutes of Health.

In the second generation of scanners, two-dimensional cross sections are still reconstructed, but a two-dimensionally divergent X-ray beam is used in place of the parallel beam so as to allow for faster X-ray times. This development mandated a return to research of basically mathematical questions; Smith and his coworkers brought to bear on this problem concepts and methods from singular integral operators, real and complex analytic functions of several variables, and operators on Hilbert spaces. Most of the results obtained have an intrinsic mathematical interest as well as importance to radiology. Theorems have been obtained that describe conditions for uniqueness, reconstruction, and optimal (or appropriate) source configurations.

Presently there is a felt need to deal with three-dimensionally divergent beams of X-rays because of the extremely fast exposure times required in the reconstruction of moving objects; a problem of major current interest is the three-dimensional reconstruction of the image of a beating heart. With humans this data must be collected during the fraction of a second in which heart movement is minimal, and this is impracticable with a succession of two-dimensionally divergent beams.

Smith and his coworkers, with NSF support, are developing models and formulas for the three-dimensional divergent beam transform. The three-dimensional problem is of a different nature than the two-dimensional one in that only partial information is available from each X-ray source; within this context, it becomes particularly important to determine appropriate theorems for uniqueness of image reconstruction and for appropriate distribution of sources.

Computer Science

The intellectual range of computer science includes and may be coextensive with the rigorous study of what is feasible. While it is true that any known cognitive, analytical, or design activities that can be described in words, numbers, or pictures could be coded and simulated on a computer, most such activities cannot be performed in reality because they are too complex to be feasible. This central fact is appearing in one form or another in every program of NSF research in computer science; the study of complexity—its dimensions, characteristics, and implications in various contexts—is a principal focus of attention. Today, researchers in software engineering, computer systems, and theoretical computer science are beginning to see common ground of mutual interest; it is becoming increasingly clear that they share a common bond in science.

Such, of course, has not always been the case. Most of the early development of digital computers and associated software took place in universities with small groups of researchers experimenting with new equipment designs and programming techniques. As the value of computers to the academic world became apparent, they became an essential part of every campus. This spawned the discipline of computer science.

During the 1960's, the formative years for most computer science departments, researchers tackled isolated problems with the few tools at hand. There were few general principles and little interaction with research on allied problems. By the end of the decade, however, there were efforts to discover the unifying principles underlying the art and recognition of the relationships among its various subdisciplines. This period also saw the development of university computer centers, many of which were funded by the NSF. Besides providing computing power to the general academic community, they provided an experimental test bed for computer scientists as they developed new programming languages, operating systems, and time-sharing systems.

Perhaps the most striking change in computer science in the 1970's has been the discipline's increased concern with the computing process itself, as distinguished from the art of getting answers. With respect to directions of research, clear trends include a surge of activity in theoretical computer science and a substantial shift of focus in software and programming systems research toward greater formalization in studying programs as structured objects with semantic content.

Software engineering has emerged as an interrelated set of issues concerned with the design and production of computer software. There has been a broadening of interest in intelligent systems and other forms of nonnumeric research and applications. There also has been growth in university-based research in experimental systems.

Analyzing and Testing Computer Programs

Although software production requires considerable human insight and ingenuity, many critical software activities are quite mundane. Quality control is among them. In order to achieve a product of high quality, much effort must be devoted to documentation and reporting; production, inspection, and verification of detailed specifications; and attempts to maintain up-to-the-minute communication in the face of inevitable change. Because these activities are so mundane and usually performed solely by humans, they are error-prone, expensive, and often incomplete.

In the past several years there has been intense activity in the creation of computerized tools and aids for analyzing and testing computer programs. This work has brought into existence a bewildering variety of capabilities. A research team at the University of Colorado, headed by Leon J. Osterweil and Lloyd D. Fosdick and supported by a grant from NSF, is synthesizing these capabilities into a unified methodology. It is expected that this methodology will provide guidance in the selection and coordination of tools and toward the goals of more effective testing, more comprehensive and accurate documentation, more definitive determination of the presence of errors in programs, and better communication between members of a software production team.

Software tools can be categorized into three classes: static analysis, symbolic execution, and dynamic analysis. Static analysis, which occurs before a program is written, is used to eliminate easy-to-locate errors and frequently determines which program execution paths might be error-prone. Symbolic execution involves the use of analytic expressions to describe the results of following particular paths in a program and is best suited for use in proving programs correct. Dynamic analysis is the name for various techniques for detecting errors during execution. These techniques are most effective in exploring the nature of known errors.

The essence of the work of Fosdick and Osterweil is to show that these classes of tools can be interfaced to each other in efficient and truly complementary ways. This is partly a question of determining optimal information flows, partly a question of understanding better the essential capabilities of the various classes of tools, and partly a question of understanding and organizing better the actual software production process that is to be aided. In order to explore these ideas, they are attempting to synthesize a prototype capability out of existing software tools already on hand.

Understanding Vision

Trying to understand how human vision works and how visual perceptions are transformed into words has inspired a significant body of intriguing scientific research over the past two decades. Many of the ideas that determine the directions of contemporary research in this field stem from an inclination to apply concepts that describe intricate computer-based electro-optical imaging systems. The question as to how complete a theory of human vision can be constructed from such concepts has emerged as a key issue.

Significant progress in understanding vision has been achieved through a blending of four major scientific methodologies. The first of these proceeds through detailed empirical investigations of the neuroanatomy and biochemistry of the eye and related regions of the brain; the second involves experimental determination of the phenomena of human visual perception, and the verbalization of these perceptions, for a wide range of controlled stimuli. By these methods researchers seek to determine structure and function.

A third methodology arose from the discovery, over the past half-century, of many new analog and digital techniques for forming, recording, and manipulating images. In this context it seems natural to model human vision with those concepts from optics, photographic science, and information theory that have been so successfully employed in devising the ingenious new image systems.

The fourth methodology, computer vision, develops a suggestive analogy between general characteristics of human vision and artificial systems of image sensors linked to a computer by broad-bandwidth communication channels. The computer may be programmed to "segment" and "label" the video data, that is, to decompose the images automatically into parts that correspond to familiar entities having conventional linguistic descriptions.

This "image understanding" school of thought in computer vision is based on the observation that, in human vision, correct segmentation and labeling seem to require an interplay between the raw data detected by the retina and a database of world knowledge stored in the brain. Concepts from artificial intelligence, pattern recognition, and computer science are all invoked to develop schemes for representing classes of world-knowledge in computer-compatible form and to design computer programs that iteratively alter the segmentation and labeling of the image until consistency with the world-knowledge has been achieved.

An example of the fourth methodology, the VISIONS system developed by Edward M. Riseman and Allen R. Hanson at the University of Massachusetts, Amherst, is designed to segment and interpret color images of outdoor scenes. The VISIONS system contains two major subsystems. First, a "low-level" subsystem processes the large numeric arrays of image data. Then, this is fed to "high-level" interpretation processes which construct a description of the world portrayed in the scene. The output of the system is a symbolic model of the three-dimensional world, including the names of objects and their places in three-dimensional space, with some ability to predict the general appearance of the scene from alternative points of view. The emphasis of the current research project is on knowledge-directed scene interpretation.

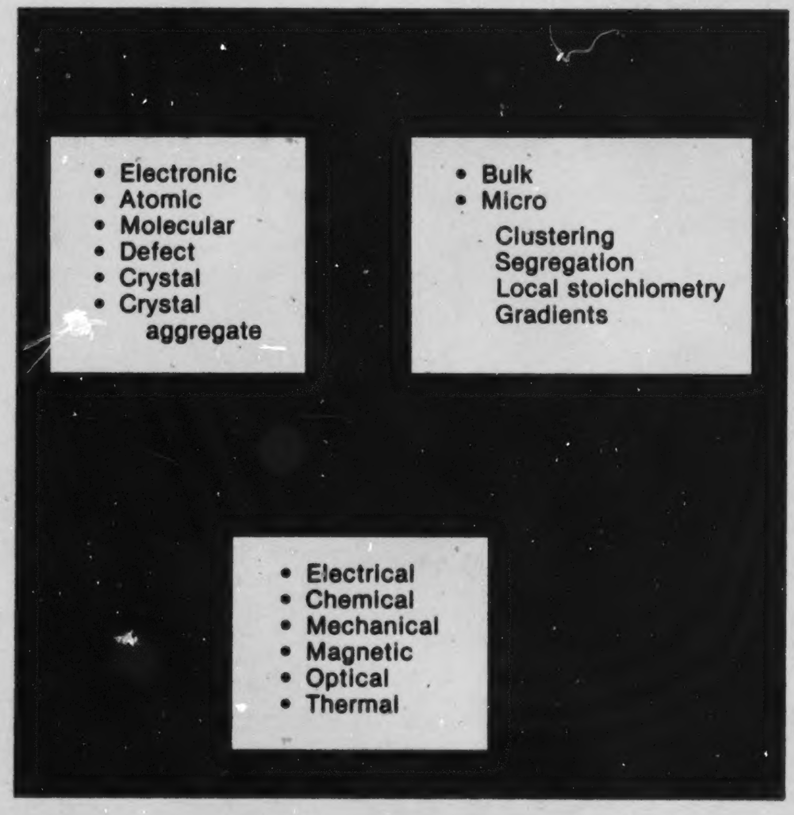
Potential applications of research in man-machine dialog about the visual world include biomedical image processing, assembly line automation, visual inspection tasks, photo-reconnaissance, and prostheses for the visually handicapped. The VISIONS system represents a valuable contribution toward resolving the issue as to how completely computer vision systems can emulate human performance.

Materials Research

Materials affect every aspect of our civilization to some extent. They are critically important (and often limiting) in energy-producing systems, in manufacturing, in national defense, in environmental matters, and in our ability to compete economically with other nations. Fundamental research supported by NSF's materials research programs provides the scientific underpinnings leading to long-term technological advances and progress in these and other areas of national interest.

Materials research is a broad interdisciplinary and multidisciplinary field. It has as an underlying theme exploration of the influence on the bulk properties of materials of their structure and microchemical composition. The research is conducted in disciplines including metallurgy, ceramics, polymer science, solid-state chemistry, and low-temperature physics, both by individuals or small specialized teams and by interdisciplinary teams such as those working at the Materials Research Laboratories.

On another scale, NSF is also steward for certain major facilities and installations—such as the synchrotron radiation facilities at Stanford University, at the University of Wisconsin at Madison, and at Cornell University; the National Magnet Laboratory at the Massachusetts Institute of Technology; and the NSF National Center for Small-Angle Neutron Scat-



Properties. Materials research tries to identify and understand the underlying principals connecting the properties and behavior of condensed matter with its structure and composition.

tering Research at Oak Ridge National Laboratory. These provide major opportunities for advancing the scientific frontiers not only of materials research, but of chemistry, biology, and other disciplines as well.

Two developments in the past year, from the subfields of materials research dealing with surface and interface science and with amorphous solids, illustrate the interplay among the ways in which materials scientists organize themselves. Each research area has aspects supported by each of the programs and by the Materials Research Laboratories. Additionally, substantial contributions to these important areas also come from work done at the special facilities.

In the area of surfaces and interfaces, which play an extremely important role in determining and influencing the properties of materials, progress has been made in understanding the structure of and chemical segregation at grain boundaries in crystalline solids, using advanced high resolution and analytical electron microscopy. Results from such studies provide new insights about the mechanical behavior of materials. Also, sophisticated surface analytical instrumentation, such as electron, photon, and ion probes, was used to determine the structure and chemical composition of solid surfaces. These techniques provide basic information leading to a better understanding of heterogeneous catalysis, corrosion, surface diffusion, friction, microelectronics, fracture, and adhesion.

In the area of amorphous solids, the atoms or molecules of which are not arranged in a regular, periodic lattice array and which include glass ceramics, amorphous polymers, metallic glasses, and amorphous semiconductors, there has been progress on several fronts. Glassy metals, produced by very rapid quenching of molten alloys, have been found to have unusual magnetic, superconducting, mechanical, and corrosion properties. Also, theoretical concepts from condensed matter science have provided important insights to understanding the behavior of electrons in amorphous semiconductors, which show much promise in the future development of electronic devices and solar photovoltaic devices.

Fundamental advances are also being made in determining the structure of amorphous solids. Particularly impressive has been the use of the extended X-ray absorption fine structure (EXAFS) technique made possible by the availability of synchrotron radiation sources for determining atomic bond distances and angles. Small-angle neutron scattering is bringing a new sense of excitement to polymer science; this technique is already enabling polymer scientists to observe the behavior of individual molecules in the bulk.

Additional areas in which scientific advances in materials research have occurred in the past year include:

- Research in solid-state physics, which has increased our understanding of the electronic structure and excitations in solids concerned with such new phenomena as electron-hole droplets, charge density waves, and high-directional electrical conductivity in layered structures.
- Condensed matter theories, which have advanced our understanding of critical phenomena and phased transitions. This research has applications to liquid crystals, spin-glasses, polymers, and adsorbed layers on surfaces.
- Research in solid-state chemistry, which has promoted understanding of quasi one- and two-dimensional systems with unusual electrical properties. One result is a new class of substances with rapid switching and memory capability.
- Low-temperature physics, where advances have been made in determining the nature of electrons trapped on the surface of liquid helium. The search continues for knowledge leading to superconducting materials with higher transition temperatures.
- Corrosion, in which metallurgists have advanced basic knowledge through high-temperature chemistry and aqueous electrochemical studies. New techniques, such as surface chemistry modification by ion implantation, provide for future progress in developing alloys more resistant to corrosion, erosion, and wear.
- A combined experimental and theoretical approach that is making significant progress in elucidating the way in which segments of polymer molecules or whole polymer molecules undergo various types of motions. These motions directly affect the observed bulk properties of plastics and rubber.
- "Phase-transformation-toughening" of ceramics, concepts of which were developed by ceramic scientists working with researchers in solid mechanics. In the long term, ceramics more resistant to fracture may be developed.

Despite much scientific progress by materials researchers in the past, there are numerous present and future needs and opportunities for basic research in this important field of science. The four scientific highlights below illustrate in greater detail specific recent accomplishments made by NSF grantees.

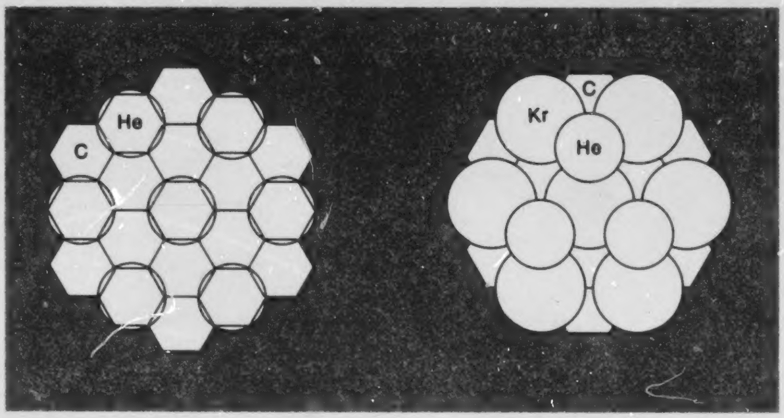
Phase Transitions in Adsorbed Films

There has been substantial progress towards a comprehensive understanding of the properties of thin films adsorbed on substrates. An important example of this progress has been the theoretical prediction and subsequent experimental verification by scientists at the University of Washington of the detailed behavior of an adsorbed layer near a phase transition. The theorists predicted, and the experimentalists confirmed, the precise way that the specific heat of a submonolayer helium film on a substrate of graphite coated with krypton would diverge at the temperature where the monolayer becomes disordered.

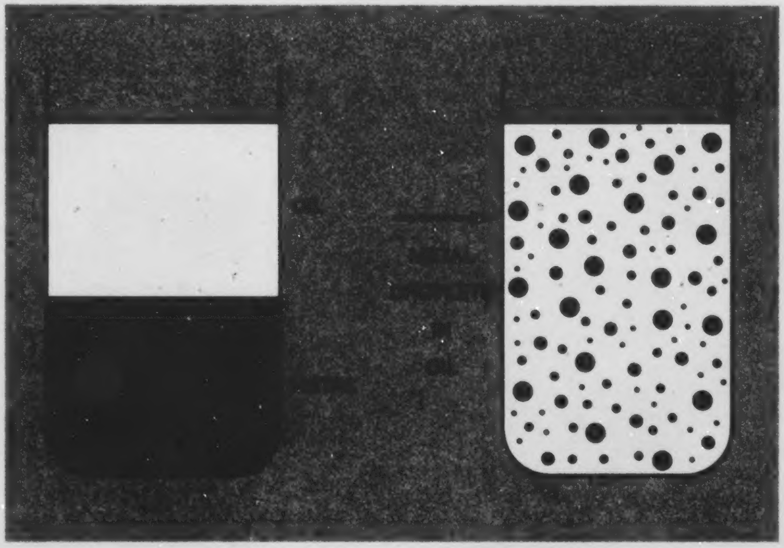
By contrast, for an adsorbed layer of helium atoms on a bare graphite substrate, the specific heat diverges differently. And in a match of "form" to "function," it has been found that, in the case [illegible] the bare graphite, an adsorbed helium [illegible] sits in a site of hexagonal symmetry, whereas, if the graphite is coated with krypton atoms, its symmetry is triangular.

This demonstrated ability to predict the nature of the phase transition from considerations of the symmetry of the substrate and interactions between the adsorbed atoms represents a significant advance in surface science. It dramatically confirms the idea that the properties of adsorbed layers can be described by relatively simple mathematical models and, conversely, that the mathematical abstraction of a "two-dimensional system" can be realized in nature as an adsorbed film.

Many other types of transitions can occur, and theories have been developed that allow a classification scheme for all types of adsorbed layers on different symmetries of substrates. These theories are quite general and also apply to *chemisorbed* systems such as hydrogen and oxygen on nickel surfaces, as well as the simple *physisorbed* systems described here. It is expected that these theoretical advances will lead to an enhanced understanding of a wide variety of surface phenomena. The theoretical work was done by Eytan Domany, Michael Schick, and J. S. Walker of the University of Washington and Robert Griffiths of Carnegie-Mellon University. The measurements were made by a group headed by Oscar Vilches at Washington.



Predictions from symmetry. Helium atoms, when adsorbed on the surface of bare graphite or graphite coated with krypton, will occupy different sites, resulting in hexagonal symmetry on the left and triangular on the right. New theories on adsorbed layers permit predictions, based on knowledge of such symmetry, of changes in physical properties near phase transitions.



Droplet emulsion technique. By using high-rpm agitation, scientists can disperse molten metal in an oil, then study the metal's solidification behavior as it is cooled. Results should be applicable to improving techniques for producing commercial alloys.

Heterogeneous Nucleation During Solidification of Metals

Under most conditions, the solidification of a liquid metal is initiated by the nucleation of a crystal at some catalytic site. Nucleation, in fact, is an important aspect of all phase transformations. In practice there may be several different types of sites present in contact with a liquid, including impurities, foreign inclusions, and container walls. While different sites are expected to possess a different potency for catalyzing crystallization, as measured by the amount of "undercooling"—cooling below the melting point—required for solidification, it has been difficult to establish a complete understanding of the factors that determine the potency of a particular site.

John Perepezko at the University of Wisconsin has developed an improved technique, called the droplet emulsion method, to evaluate the heterogeneous nucleation behavior of solidifying molten metals. In this technique, a molten metal is dispersed into fine droplets in an inert carrier fluid in order to isolate active nucleation catalysts.

Perepezko found the proper combination of organic carrier fluid, oxidant, and acid catalyst to produce the stable metal droplets needed to determine the undercooling behavior, and obtained two important results: First, a significant increase in the degree of undercooling was achieved, compared with conventional solidification methods. Second, it was determined that during heterogeneous nucleation of a liquid-solid mixture, the second solid to crystallize from the liquid need not be the equilibrium solid phase. Structural examination by X-ray diffraction demonstrated that a nonequilibrium phase can be formed during heterogeneous nucleation.

This result is significant because in all previous work it had been assumed that only equilibrium phases are involved in heterogeneous nucleation. Clearly it is not possible to understand the catalytic potency of a given heterogeneous nucleation site unless the type of structure that is nucleated on this site is known.

Experiments are in progress to evaluate the undercooling and heterogeneous nucleation behavior of a number of alloy systems with the goal of ascertaining the factors that influence the potency of various catalytic sites. The results of these experiments are expected to clarify the role played by grain refining agents added to commercial castings to improve strength and improve compositional homogeneity.

Anomalous Scattering Using Synchrotron Radiation

It has long been known that when the wavelength of an X-ray photon scattered by an atom is near an energy absorption threshold of the atom's inner-shell electrons, unusual behavior results. These anomalous scattering effects can be described in terms of the large changes introduced into the atomic scattering factor. The magnitudes of the effects are generally small when one is well away from these thresholds or "absorption edges" (as is usually the case when doing a scattering experiment with a conventional X-ray source). But the tunable X-ray diffraction facility at the Stanford Synchrotron Radiation Laboratory (SSRL) has revolutionized this classical review of anomalous scattering.

The SSRL diffraction resource can be used so that the X-ray wavelength can be tuned directly to the absorption edge of any element and thus maximize the anomalous scattering effects. By making measurements at wavelengths on either side of an absorption edge, two important benefits are realized: (1) The contribution of specific atomic species to the diffraction pattern can be identified, and (2) the classic "phase probem" can be solved. (In any diffraction experiment, only the magnitude of the scattering is measured. It is not possible to measure directly the phase of the scattered X-rays, which is necessary to determine the electron density in the material being studied and from which the crystal structure is determined.)

The work of David Templeton at the University of California, Berkeley, and Keith Hodgson at Stanford University has now resulted in a general method for measuring the anomalous scattering terms. These experimental studies provide new insight into the physics of anomalous scattering and set the stage for the application of these effects.

Anomalous scattering promises to add significantly to our ability to determine atomic arrangements in amorphous materials. Frequently, it is impossible to determine uniquely the atomic arrangement in an amorphous alloy of a type called A-B (containing atoms of two kinds—such as germanium and selenium—A and B) because X-ray, electron, or neutron diffraction experiments yield weighted sums of the A-A, A-B, and B-B partial pair distribution functions; knowledge of the *individual* partial functions would be required for an unambiguous analysis. Such individual partial functions can be obtained through neutron diffraction studies using three samples of the alloy containing different isotopes having different scattering cross sections. Unfortunately, such isotopes are available in only a limited number of cases, and large samples are required.

Recently, Paul Fuoss, William Warburton, and Arthur Bienenstock at Stanford University have examined the amorphous germanium-selenium system and successfully obtained individual germanium-germanium, germanium-selenium, and selenium-selenium partial pair distribution functions by measuring the X-ray diffraction intensities at three specific photon energies. The success of this approach means that one is able to obtain considerable structural information about amorphous alloys not obtained by any other approach.

Amorphous scattering studies using synchrotron radiation can be expected to provide considerable information about alloys and compounds of materials containing two atomic species that differ in atomic number by less than 3 or 4. Frequently, it is impossible to solve a crystal structure uniquely in such cases because the X-rays cannot distinguish between the atomic scattering factors of the two atoms. With tunable synchrotron radiation, however, one can obtain two different X-ray diffraction intensity measurements, which allow for elimination of the ambiguity.

Harry Yakel at Oak Ridge National Laboratory has used this approach to determine the distribution of cobalt and iron atoms among the tetrahedral and octahedral sites in a cobalt-iron spinel crystal. The measurement and subsequent analysis have demonstrated that cobalt and iron ions are not distributed over the sites in the theoretically expected manner.

Motions of Polymer Chains

Polymer molecules are macromolecules that consist of long, flexible chains that are subject to mutual entanglement. These chains are not static at normal temperatures but undergo a variety of motions, e.g., worm-like wriggling of segments of the chain or "backbone," motions of small side chains attached to the backbone, or motions of the entire chain. The nature and frequency of these motions have an important bearing on the bulk properties of polymeric materials, including the industrially important plastics and rubber. A number of new approaches are being taken to relate observed properties to specific molecular motions.

Recently, Walter Stockmayer at Dartmouth College has used a combination of instrumental techniques to study the rates and equilibria of shape changes in the polymer chains. These changes arise from the fact that the chemical bonds linking the atoms of the backbone can rotate and thereby change the overall shape of the polymer molecule. He found that solutions of poly(olefin sulfones), when subjected to dielectric relaxation, gave results best interpreted as due to relatively slow overall tumbling of the whole chains, as well as very rapid localized motions that reorient the molecule's carbon-hydrogen bonds but do not change its electric polarization.

C. H. Wang at the University of Utah and John Schrag at the University of Wisconsin have found other shape changes tied to that localized segmental motion. Schrag is further studying polymer solutions subjected to sinusoidally time-varying shear flows and is finding that the results can be correlated with motions of the side chains attached to the backbone and to segmental motion.

The effect of entanglements of the flexible chains has been recently studied by John Ferry at the University of Wisconsin. He finds that each molecule behaves as though it were entangled with some neighbors to form a temporary crosslinked network structure. Ferry's approach has been to stretch a rubbery polymer, cool it to a temperature at which the material becomes glassy and the chains are immobilized, and then to introduce permanent, chemical crosslinks by high-energy radiation. The properties of the resulting structure are then observed. Its behavior is found to be described accurately by a model in which a trapped entanglement network seeks to bring the sample back to its original unstretched state as the crosslinks are being introduced. When released and warmed, the sample retracts to an intermediate state of stretch. These molecular motions underlie the mechanical properties of amorphous polymers and rubber.

Astronomical, Atmospheric, Earth, and Ocean Sciences

2

The research supported by NSF in the Astronomical, Atmospheric, Earth, and Ocean Sciences (AAEO) not only encompasses the physical and chemical characteristics of the Earth and its surrounding atmosphere but extends beyond into the far reaches of the universe. The boundless geographic limits of AAEO-supported research are echoed in the time span under investigation: astronomical studies of the birth of the universe billions of years ago; research on the more recent past and the present environment here on Earth; even a look into the future in studies of weather and climate phenomena, the movement of the continents indicated by plate tectonics theory, and a cosmological view of the death of the universe.

The major portion of AAEO research investigates those conditions and processes present and operating today. This research enables more accurate assessments to be made of the environment and lays the foundation for assessing the impact of our interaction with our surroundings.

NSF's astronomy programs are the primary source of support for U.S. ground-based astronomy. In addition to research grants to academic institutions, support is provided for five national astronomy centers that operate some of the largest and most advanced optical and radio telescopes in the world. Construction of the Very Large Array (VLA) radio telescope and its 27 antennas along a wye track located in New Mexico is nearing completion. Partial operation of the VLA has increased from 12 to 17 antennas in use simultaneously.

Significant events in astronomy during 1979 include the discovery of narrow radio jets extending hundreds of thousands of light years into space from the center of a galaxy, possibly as a result of stars being swallowed by a large black hole; the discovery of a unique double quasar, first observed optically at Kitt Peak National Observatory and later with the VLA; and the first experimental evidence of the existence of gravitational waves.

NSF provides almost half of the Federal support for university-based atmospheric sciences research. Begun a few years ago, the Global Atmospheric Research Program (GARP) has been the vehicle for several worldwide atmospheric experiments. During 1979 the GARP Monsoon Experiment was conducted over India and its surrounding ocean.

In addition to its grants to universities, NSF supports the National Center for Atmospheric Research (NCAR) in Boulder, Colorado, and the National Scientific Balloon Facility (NSBF) in Palestine, Texas. NCAR and the NSBF are operated by a consortium of universities

Table 2
Astronomical, Atmospheric, Earth, and Ocean Sciences*
Fiscal Years 1977, 1978, and 1979

(Dollars in Millions)

	Fiscal Year 1977		Fiscal Year 1978		Fiscal Year 1979	
	Number of Awards	Amount	Number of Awards	Amount	Number of Awards	Amount
Astronomy	222	$ 13.48	227	$ 15.65	248	$ 16.34
Atmospheric Sciences	276	17.66	295	20.15	334	21.58
Global Atmospheric Research Program	67	4.46	69	5.28	70	5.66
Climate Dynamics	59	3.97	70	4.31	71	4.74
Earth Sciences	325	16.26	442	20.67	503	24.92
Ocean Drilling Programs	4	12.80	5	13.40	4	11.62
Ocean Sciences	322	17.70	351	19.00	362	19.74
International Decade of Ocean Exploration	190	17.16	234	18.37	240	19.46
Oceanographic Facilities and Support	69	18.39	70	20.81	60	23.20
U.S. Antarctic Research	115**	45.29	132**	48.45	140**	51.09
Arctic Research	58	4.62	78	5.34	87	5.97
Total	1,707	$171.79	1,968	$191.43	2,119	$204.32

* Excludes National Research Centers.

** Science Awards. Excludes operations support awards.

SOURCE: Fiscal Years 1979, 1980, and 1981 Budgets to Congress—Justification of Estimates of Appropriations (Quantitative Program Data Tables).

The reaches of AAEO. This ATS III Satellite picture, taken over South America, reflects the scope of research concerns reported in this chapter—the solid Earth, the oceans, the polar regions, the atmosphere, and the planet as an astronomical body.

and coordinate long-term, cooperative research between universities and other Federal agencies on scientific problems of national and international importance. Facilities include a state-of-the-art scientific computer system, aircraft, balloon launch, and radars. Investigations of upper atmospheric plasma convection; climatic variability, particularly in the Southern Hemisphere; acid precipitation; and severe convective storms yielded significant results in 1979.

The field of earth sciences, including geology, geophysics, and geochemistry, continues to receive increased attention—from the global scale of plate tectonics theory to the microscopic view of mineral formation. The technique of seismic reflection profiling has improved earth scientists' concept of the deep crustal structure of selected areas of the North American Continent by providing evidence for various theories regarding fault delineations and other deformations. The Deep Sea Drilling Project has developed a new technological device, the hydraulic piston corer, that produces cores in which soft sediment layers are distinctly visible.

Oceanographic research projects on the chemistry, biology, geology and geophysics, and physical properties of the oceans and ocean basins are supported through multiinstitutional grants, as well as through grants to individual institutions. Large-scale, multidisciplinary projects, as part of the International Decade of Ocean Exploration, are designed to develop a comprehensive understanding of various marine environments and phenomena.

Among the successful undertakings in 1979 was a study of nitrous oxide concentrations in the lower atmosphere and surface seawater, one of the many chemical cycles under investigation. An unusual and exciting discovery, made off the East Pacific Rise and recorded by a camera mounted on the submersible vessel *Alvin*, was an area of "chimney" structures spewing hot (350°C) water laden with various minerals. The academic fleet, of which *Alvin* is a component, is supported almost entirely by NSF and now numbers 28 ships. A new coastal ship will be constructed with FY 1979 funds as part of

Table 3
Astronomical, Atmospheric, Earth and Ocean Sciences
National Research Centers
Fiscal Years 1977, 1978, and 1979

(Dollars in Millions)

	Fiscal Year 1977	Fiscal Year 1978	Fiscal Year 1979
National Astronomy and Ionosphere Center	$ 3.90	$ 5.48	$ 4.62
Kitt Peak National Observatory	8.70	9.13	9.70
Cerro Tololo Inter-American Observatory	3.50	3.88	4.35
National Radio Astronomy Observatory	21.80	22.14	22.70
National Center for Atmospheric Research	23.04	24.90	25.26
National Scientific Balloon Facility	*	1.77	1.87
Sacramento Peak Observatory	0.80	1.30	1.50
Total	**$61.74**	**$68.60**	**$70.00**

*Included under the National Center for Atmospheric Research in previous years.

SOURCE: Fiscal Years 1979, 1980, and 1981 Budgets to Congress—Justification of Estimates of Appropriations (Quantitative Program Data Tables).

the trend toward smaller, more efficient vessels for the increasing amount of research on the continental margins.

NSF is one of several Federal agencies supporting research in the Arctic and has the sole responsibility for the U.S. research activities and Antarctic program. Maintenance of facilities and logistical support for research activities are major components of the U.S. presence in Antarctica. Included among the polar program projects carried out during 1979 were investigations of the source of the heavy haze observed over the Arctic Ocean, the thickness of the Greenland ice sheet, the life cycle of the Antarctic krill (*Euphasia superba*), and the evolution of the Ross Ice Sheet.

Astronomy

In fiscal year 1979 the Foundation supported basic research in astronomy at more than 70 universities, private observatories, and federally owned observatories. This support came in the form of research grants and allotment of scheduled use (observing time) of telescopes and other instruments at national or regional observatories.

The Foundation's astronomy project support program makes grants in all topical areas of ground-based astronomy. These include the Sun and other bodies of the solar system, the composition and behavior of stars, systems of stars, motions of stars, and the composition and behavior of gas and dust throughout interstellar space. Advanced technology is increasingly important for extracting information from light and radio waves received from the large variety of distant objects. For this reason, in addition to awards for research, the program supports development and procurement of new instrumentation.

Under awards made in 1979, about 350 scientists and 200 graduate students were involved in research and the development of new techniques. Several major U.S. astronomy observatories, including the five NSF-supported National Astronomy Centers, participated in projects supported under this program. University-operated observatories assisted under this program are: the Five College Radio Astronomy Observatory in Massachusetts—site of an excellent millimeter-wave antenna; the Owens Valley Observatory in California—site of a three-element radio interferometer; the Hat Creek Observatory in California—site of a two-element millimeter-wave interferometer; and the Haystack Observatory in Massachusetts—which operates a 37-meter-diameter radio telescope as part of the international very long baseline interferometry network.

The National Science Foundation is also responsible for support of the Nation's five National Astronomy Centers: the National Astronomy and Ionosphere Center (NAIC), Kitt Peak National Observatory (KPNO), Cerro Tololo Inter-American Observatory (CTIO), the National Radio Astronomy Observatory (NRAO), and Sacramento Peak Observatory (SPO). These centers enable astronomers at universities, Federal laboratories, and industrial organizations throughout the Nation to use the advanced or unique instrumentation required for forefront research.

The centers maintain and develop an array of telescopes, instruments, and facilities that are among the most advanced in the world for investigations in radio, millimeter, infrared, optical, and solar astronomy. Because most astronomers are at universities without research quality telescopes, these National Centers are a vital resource for astronomy.

Gravity Waves

In December of 1978 three astronomers at the University of Massachusetts announced the first experimental evidence directly supporting the existence of gravitational waves. Such waves, long hypothesized but never directly observed, are in some ways similar to radio waves, but are based on the forces of gravity rather than on those of electricity and magnetism. The existence of gravity waves is one of the longstanding but heretofore untested predictions of Einstein's general theory of relativity.

The discovery came out of an observing program spanning four years to measure the general relativistic effects in the binary pulsar PSR 1913+16. The pulsar, located some 15,000 light years from Earth, was observed with the 305-meter-diameter radio antenna operated by the National Astronomy and Ionosphere Center. Discovered in 1974 by the same research group, it is known to be orbiting another massive object—perhaps another pulsar, or perhaps a black hole—because its repetitive pulses of emission speed up and slow down over a period lasting a little less than 8 hours.

Einstein's theory predicts that such a system should emit gravitational waves that slowly extract energy from the orbit, thereby causing the pulsar and its companion to move closer together. As the size of the orbit decreases, the length of time required for the pulsar to complete an orbit also decreases. Relativity theory predicts that the orbital period in this case should decrease at a rate of one ten-thousandth of a second per year. The measured amount is almost precisely this value, or about four ten-thousandths of a second since late 1974.

Thus an important prediction, based on an application of Einstein's theory that could not have been foreseen when Einstein developed the theory 60 years ago, has been verified. This finding will give much impetus to experimental work, underway at numerous laboratories around the world, directed to actual detection of the gravitational waves themselves, as well as to further theoretical studies of the theory of relativity. The three scientists who performed the research are Joseph Taylor and Lee Fowler of the University of Massachusetts at Amherst and Peter McCulloch, who is on leave from the University of Tasmania, Australia.

Changing orbit. Four-year observations of the orbital period of a pulsar circling another massive object show a decrease that matches that predicted by gravitational effects in Einstein's General Theory of Relativity. This finding strongly supports the existence of gravitational waves, which are yet to be detected directly.

Pulsars are believed to be the remains of dying stars that have exploded, leaving behind small, rapidly spinning remnants so dense that a teaspoonful of the material weighs a billion tons. Millions of pulsars are thought to exist in the galaxy, although most of them are invisible to even the most sensitive radio telescopes. About 320 have been detected, mostly by the University of Massachusetts group and other research groups in England and Australia.

Only one pulsar, the one used in the present study, is known to be a member of an orbiting pair. Because it moves at a speed of over 950,000 kilometers per hour and is subject to the very strong gravitational forces exerted by its companion, this pulsar is uniquely well suited for detection of the effects of gravitational waves.

Cosmic Jets

There has been intense interest in recent years in the study of the central cores of galaxies. There are a number of reasons, including the possibility that certain galactic nuclei generate the prodigious amounts of energy needed to power giant radio wave sources, that others may be responsible for the enigmatic quasar phenomenon, and that still others may be the sites of massive black holes.

However, there is also evidence, from very long baseline radio interferometry (VLBI) and studies of variability timescales, that the physical dimensions important in these types of nuclear activity are several orders of magnitude smaller than can be resolved by any single existing or planned telescope system. Astronomers are, as a consequence, limited to investigation of the various large-scale effects seen to be associated with active nuclei.

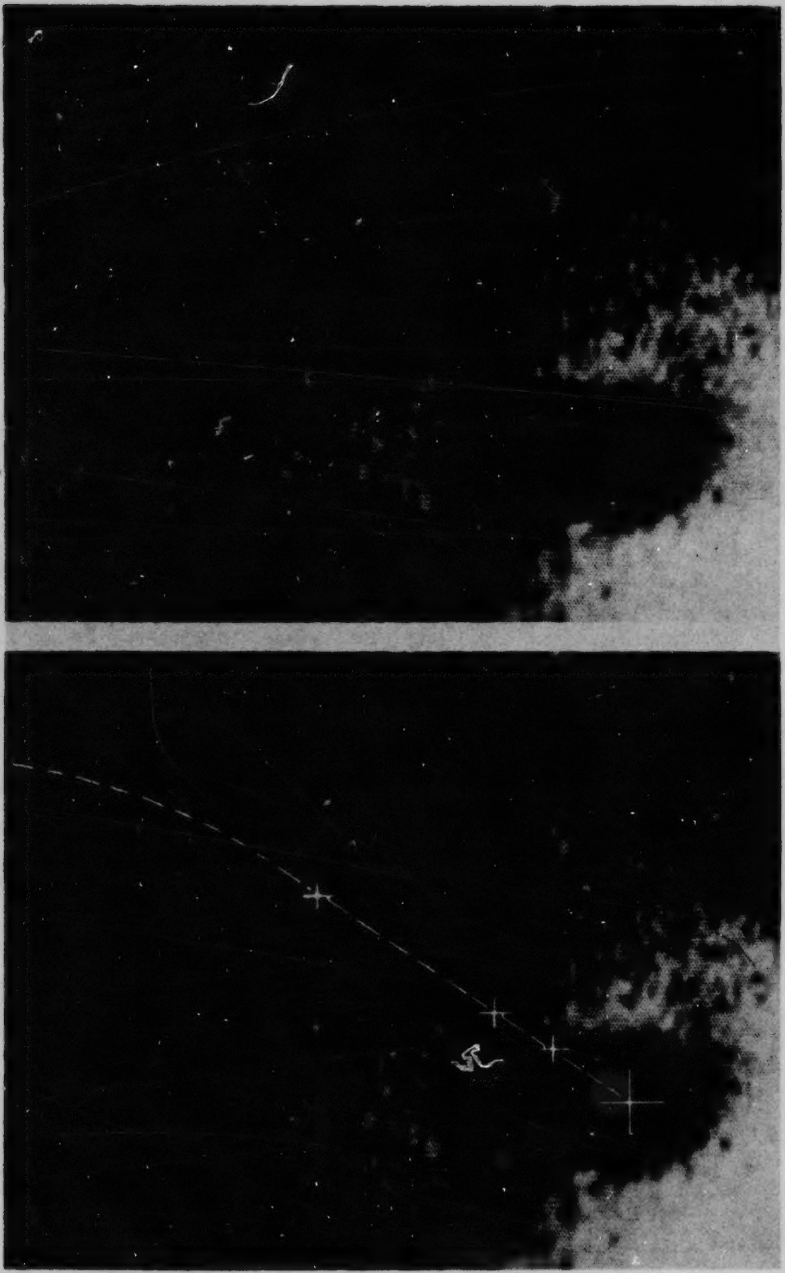
One of the more intriguing of such phenomena has been the recently discovered narrow radio jets, which may extend hundreds of thousands of light years from the center of a galaxy into neighboring space. Last year three California Institute of Technology scientists detected one such jet emanating from the very massive core of galaxy NGC 6251. This jet, which extends for a distance of 750,000 light years, indicates that the core of the galaxy is steadily pumping a large amount of energy and matter (about four solar masses per year) into space.

The violent events that cause such an outpouring of energy are the subject of much study and theoretical speculation. It is possible that NGC 6251 contains a large black hole that is swallowing stars in its vicinity. The energy released by the stars as they fall into the black hole could well account for the prodigious energy output from NGC 6251. The strong gravitational pull of a black hole accelerates collapsing stellar matter to very high velocity, resulting in a series of violent collisions among subatomic stellar particles that produce intense X-rays, radio waves, and visible light.

The detailed radio "picture" of the jet was obtained using the technique of very long baseline interferometry. Radio astronomy antennas located at the Haystack Observatory in Massachusetts, the National Radio Astronomy Observatory in Green Bank, West Virginia, and the Owens Valley Radio Observatory in California scheduled simultaneous observations of the galaxy. Analysis of the combined radio signals produced the fine detail required to probe the interiors of the distant galaxy.

While several jets have now been studied with radio telescopes, until last year only one of these was known to emit optical (visible) light. As in other areas of astronomy, observation of an object at different wavelengths is much desired and sought after. Observation of optical synchrotron emission from jets (which would occur within a short time—a matter of years— after the energy conversion causing the emission) would permit scientists to locate precisely the sites of energy generation.

Last year, an international team of astronomers, from Kitt Peak in the United States and Leiden University in the Netherlands, used the 4-meter telescope at KPNO equipped with a sensitive digital televi-



Radio jet. New observations of galaxy 3C 66B show a clear correlation of optical features with a massive jet previously discovered with radio telescopes. The dashed line on the lower photo shows the ridgelines of the radio jet, and the plus signs indicate the brightest knots of radio emission. The optical/radio matchup indicates that the jets are probably a product of synchrotron emission, which could result from stars being captured by a nearby black hole.

sion detector to discover two additional galaxies with optical jets. These unusual galaxies, known by their radio source designations as 3C 66B and 3C 31, are large and elliptically shaped with no otherwise particularly distinguishing optical features. The precise coincidence of the discovered optical features with the brightest parts of the radio structure leave little doubt that the new jets are made visible by the same process responsible for their radio emission—the synchrotron process.

These galaxies with jets are also observed to have significant amounts of lumpy interstellar matter, as do other radio galaxies with jets. One possibility is that both the radio and optical emission may derive from beams of jet material that drive strong shock waves into this interstellar medium. Such shocks may be able to accelerate electrons to high enough energies to produce the optical synchrotron emission.

Double Quasar

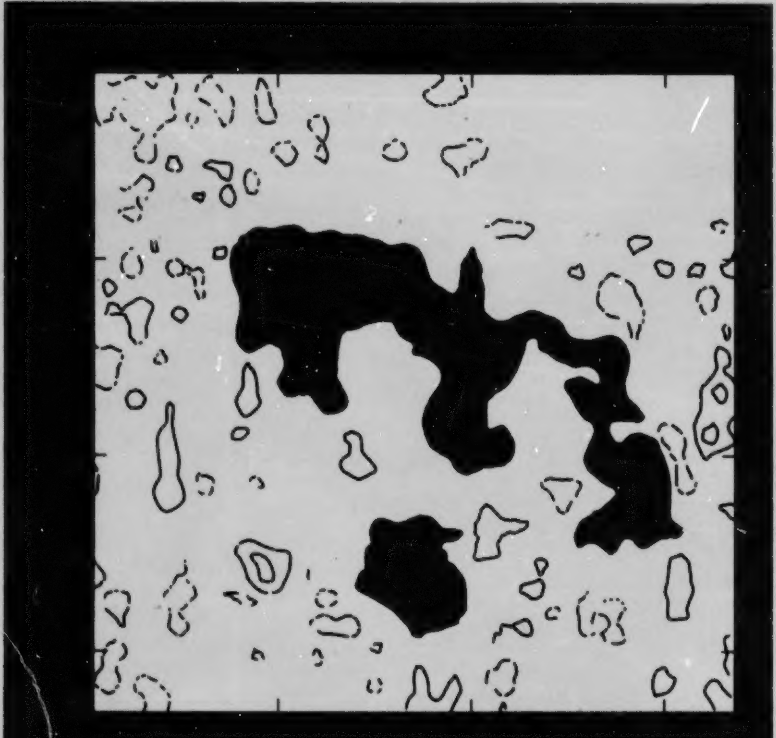
A unique double quasar has been discovered. The quasar was first detected by Dennis Walsh at the Jodrell Bank Radio Observatory in England. Its approximate position was later determined at NRAO using the Green Bank, West Virginia, 91-meter-diameter antenna. At that time the object appeared to be an ordinary quasar. Then on March 29, 1979, Robert F. Carswell of Cambridge University studied the object with the KPNO 2.1-meter optical telescope. Detailed observations revealed that the object was in fact two images separated by an angle of 5.7 arc-seconds. This finding was later confirmed by R. Weymann and others using the University of Arizona's 2.3-meter telescope on Kitt Peak and the new Multiple-Mirror Telescope operated by the University of Arizona and the Smithsonian Astrophysical Observatory.

Although binary in appearance, the two images may be the result of light from a single quasar being split by what amounts to a gravitational lens. This would require the presence somewhere between the quasar and Earth of either a supermassive black hole or a large galaxy with trillions of solar masses. As explained by Einstein's general theory of relativity, any object with large mass will noticeably deflect light rays passing near its edge. During solar eclipses astronomers can readily confirm that stars near our line of sight to the Sun's edge (limb) appear displaced by this effect.

In the case of a quasar, if an extremely massive object were close enough to the line of sight, a more dramatic effect could appear. The light beam from the quasar could be deflected in more than one direction, thus producing a double image. This explanation is supported by spectroscopic data that indicate that the twin objects, designated 0957+561A and B, have identical redshifts and nearly identical features. Also, no such twins have been observed among the other thousand known quasars.

More recently B. F. Burke, P. E. Greenfield, and D. H. Roberts of the Massachusetts Institute of Technology observed the double quasar's radiowave image. Using the Very Large Array interferometer radio telescope in New Mexico, they produced a radiowave picture (or map) of 0957+561. Again, the double image appeared. But more interestingly, they found other sources of radio emission in the radio map not detected by the earlier optical telescope observations.

It is common for a quasar or an active galaxy to expel jets of matter into the neighboring region of space, and the MIT team's radio map of 0957+561 has the appearance of a classic case of this kind of phenomenon. However, they find that only one of the two quasars is undergoing an active stage of jet expulsion; there is no similar matter associated with its twin. So, these radio wave observations indicate that 0957+561 is a genuine double quasar and that perhaps no gravitational lens need be postulated. However, the near-identical redshifts and optical features of the two quasars suggest a common origin.



Double quasars. Initial observations of two quasars, 0957+561 A and B, showed them to be so similar that a gravitational "lens" was suggested to explain them as a double image. However, more recently a high-resolution map compiled with the Very Large Array radio telescope shows that source A seems to be different from B, expelling jets of matter that appear as further radio emissions at C, D, and E. Such a feature argues in favor of a true double quasar, the understanding of which might shed light on the origin of quasars or the mechanisms by which they produce such prodigious energy.

For the present there is not enough evidence to decide whether or not the scientists are observing one quasar and one gravitational lens or two strikingly similar quasars. Future observations of time-variable changes in brightness may be required to reach a final interpretation. In any case, it is clear that the double quasar is a unique object.

Stellar Magnetic Fields

Solar flares and other manifestations of solar activity are intimately connected with the Sun's magnetic fields. A central objective of contemporary solar physics is to study how these fields are generated and how they produce the spectacular phenomena associated with solar activity. The proximity of the Sun allows these problems to be studied in great detail, providing a firm foundation for hypotheses concerning similar processes in more remote objects.

Analogs of solar activity are found on many other stars. Flare stars, for example, exhibit violent outbursts that are similar in many respects to solar flares, but involve as much as a thousand times more energy. Most stars like the Sun have chromospheres and coronas, some much more pronounced than the Sun's.

Recent work at the Hale Observatories has shown that the activity of stellar chromospheres waxes and wanes over periods of years in a manner strongly suggestive of the solar activity cycle. It has been supposed that all these phenomena are due to stellar magnetic fields, but until recently there was no way to directly detect and measure magnetic fields on solar-type stars.

Now, a staff member at SPO, Richard D. Robinson, has devised a way to directly measure the strengths and areas of stellar magnetic fields. The method relies on the Zeeman effect: The shape of a spectral line formed in a gas containing a magnetic field depends on the strength and direction of the field.

Previous applications of the Zeeman effect to measurements of stellar magnetic fields have required observations of the polarization of starlight. This is very difficult, and the methods have been unsuccessful when applied to stars like the Sun. Robinson's method is unique in requiring observations of only the total intensity of the spectral line so that the method can be used for all kinds of objects.

The first tests of the method were made by comparing magnetic and nonmagnetic areas of the surface of the Sun. Solar magnetic fields were easily detected. Robinson, with Simon P. Worden (assigned to the Air Force Geophysical Laboratory's group at SPO), and John W. Harvey of KPNO then observed several stars using the McMath Solar Telescope at Kitt Peak. A magnetic field was easily detected for the first time on the dwarf star Xi Bootis A. The field strength was 2900 gauss, covering about 45 percent of the stellar surface. By comparison, the solar field strength is about 1500 gauss, covering about 1 percent of the surface.

Since Xi Bootis A is a young star exhibiting much more prominent chromospheric activity than the Sun, this observation provides direct confirmation of an intimate connection between stellar magnetic fields and stellar activity. The new method is now being applied to systematically study magnetic fields in solar-type stars, using data obtained with th 4-meter Mayall telescope at Kitt Peak.

Cerro Tololo Inter-American Observatory

The eight optical telescopes at CTIO, which is operated by the Association of Universities for Research in Astronomy, Inc., under contract with the NSF, represent 25 percent of all the light-gathering power in the Southern Hemisphere. The major instrument is a 4-meter reflector that is the near twin of the KPNO Mayall telescope. Both telescopes are located at latitudes of approximately 30 degrees in their respective hemispheres and thus provide full-sky coverage with world-class instruments.

The CTIO headquarters facility is located in the coastal town of La Serena, Chile, approximately 80 road kilometers (50 miles) from the mountain location of the telescopes. On Cerro Tololo there are facilities to operate and maintain the telescopes and auxiliary instruments as well as lodging for technicians and observing astronomers. The La Serena headquarters contain a computing center, machine and vehicle maintenance shops, engineering facilities, a library, and staff offices and housing.

The 2,200-meter (7,200-foot)-high site on which the telescopes are clustered averages about 300 clear nights a year, of which 75 percent are unspoiled by atmospheric turbulence that can adversely affect astronomical observing. These superb conditions are the result of a meteorological phenomenon that forms a pronounced inversion layer that extends over northern Chile. Cerro Tololo projects above this layer into a clear, dry, and stable air mass. Also, the night sky is very dark because of the site's remote location.

These conditions enable scientists to use the CTIO telescopes for research on unique southern skies objects such as the central bulge of the Milky Way galaxy and the Magellanic Clouds, the closest neighboring galaxies. Other interesting objects more frequently found in the Southern Hemisphere are galactic X-ray sources, globular clusters, planetary nebulae, and the brightest hydrogen gas clouds and their related interstellar dust regions. Cerro Tololo also provides a truly representative view of intergalactic space out to a distance of 25 megaparsecs, although the northern view of the space, dominated by the extensive cloud of galaxies centered in Virgo, is not a good sample of extragalactic space for cosmological studies.

During fiscal year 1979, 69 percent of the available telescope time was assigned to 184 visiting astronomers, including 21 graduate students from 56 institutions in the United States, 5 in Latin America, and 15 in other countries. The remaining 31 percent of available telescope time was assigned to CTIO staff scientists.

Improvements to the mountain facilities during 1979 included completion of a photographic laboratory and drilling of a new water well to provide a backup water supply for the new lab and other high-volume requirements. Extensive maintenance work was carried out on the 38-kilometer (24-mile) Tololo access road, and a new power supply system was installed to compensate for frequent commercial power failures.

Kitt Peak National Observatory

Kitt Peak National Observatory (KPNO) supports visitor-oriented advanced research programs in stellar, solar, and planetary astronomy and engages in programs to develop and improve astronomical research facilities and auxiliary instrumentation. The observatory, with headquarters and laboratories located in Tucson, Arizona, adjacent to the University of Arizona, is operated by the Association of Universities for Research in Astronomy, Inc., under contract with the NSF.

The observing facilities are on Kitt Peak, a 2,000-meter (6,875-foot) mountain in the Quinlan Range, 90 kilometers (56 miles) southwest of Tucson. The site is on the eastern edge of the Papago Indian Reservation and is leased from the Papagos. Kitt Peak's combination of frequent clear weather, minimum air turbulence, remoteness from bright lights, suitable summit area, and well developed access has attracted the largest collection of optical telescopes in the world. KPNO operates 13 telescopes, including the 4-meter Mayall stellar telescope and the world's largest solar telescope, the 1.5-meter McMath.

In addition to the KPNO telescopes, the mountaintop houses optical telescopes belonging to the Steward Observatory (University of Arizona), McGraw-Hill Observatory (University of Michigan, Massachusettts Institute of Technology, and Dartmouth College), and Warner and Swasey Observatory (Case Western Reserve University), and a single radio telescope of the National Radio Astronomy Observatory. The most recently arrived of these other-observatory telescopes is Warner and Swasey Observatory's 61/91-centimeter (24/36-inch) Burrell Schmidt telescope, which was relocated from Cleveland, Ohio, during 1979.

KPNO is currently experiencing a revolution in astronomical instrumentation, with modern electronics and microcircuitry as the basis for recent developments in sensitive, low noise, array light detectors that are being put into effective use on the largest KPNO telescopes. These devices are beginning to provide measurements of the faintest detectable sources, limited only by the fundamental quantum statistics. In addition, computer-related advances in signal processing and data handling are leading to major changes in instrument design, permitting measurement techniques scarcely foreseeable a decade ago.

During fiscal year 1979, the KPNO total of 411 visiting scientists included 306 astronomers and 105 graduate students from 93 U.S. and 34 foreign institutions (15 countries). The number of visiting astronomers indicates the variety of projects sponsored by KPNO. Telescope time is assigned based on the merit of research proposals; no discrimination is made between KPNO staff members and outside astronomers. At least 60 percent of all the available observing time on the KPNO telescopes is used by visiting scientists.

Many of the KPNO stellar telescopes, including the Mayall 4-meter telescope, are used for daytime infrared observations in addition to nighttime observations. Conversely, the McMath telescope complex, designed primarily for solar observations, is used frequently for nighttime studies of planets and stars.

National Astronomy and Ionosphere Center

NAIC, with the world's largest radio/radar telescope—a 305-meter (1000-foot)-diameter fixed spherical antenna located near Arecibo, Puerto Rico—provides unique instrumentation and facilities for research in radio and radar astronomy and atmospheric physics. Facilities and support services are available, free of charge, on an equal and competitive basis to visiting scientists from all over the world. NAIC is operated by Cornell University under contract with NSF.

Preparations were made during 1979 for a number of new programs to be available during the coming year. The 30-meter-diameter steerable antenna located 10 kilometers north of the main telescope, and previously used only for radar interferometry studies, is now available for radio astronomy interferometric observations. The S-band planetary radar system will be available for stratospheric studies. The new high-frequency ionospheric modification facility will be available for ionospheric heating experiments and the investigation of parametric instabilities and nonlinear processes in the ionospheric plasma.

Telescope upgrading activities are practically complete. The reflector surface has been surveyed and faired to bring the entire 305-meter surface (approximately 8 hectares) very close to a true spherical surface. The pointing accuracy of the telescope has been improved by reducing errors in the drive and servocontrol systems. A pointing accuracy of better than 10 arc-seconds rms in each coordinate has been achieved for the S-band transmitting feed.

New equipment, observational techniques, and computer programs are continually being developed to make visitor use of the Arecibo systems more efficient.

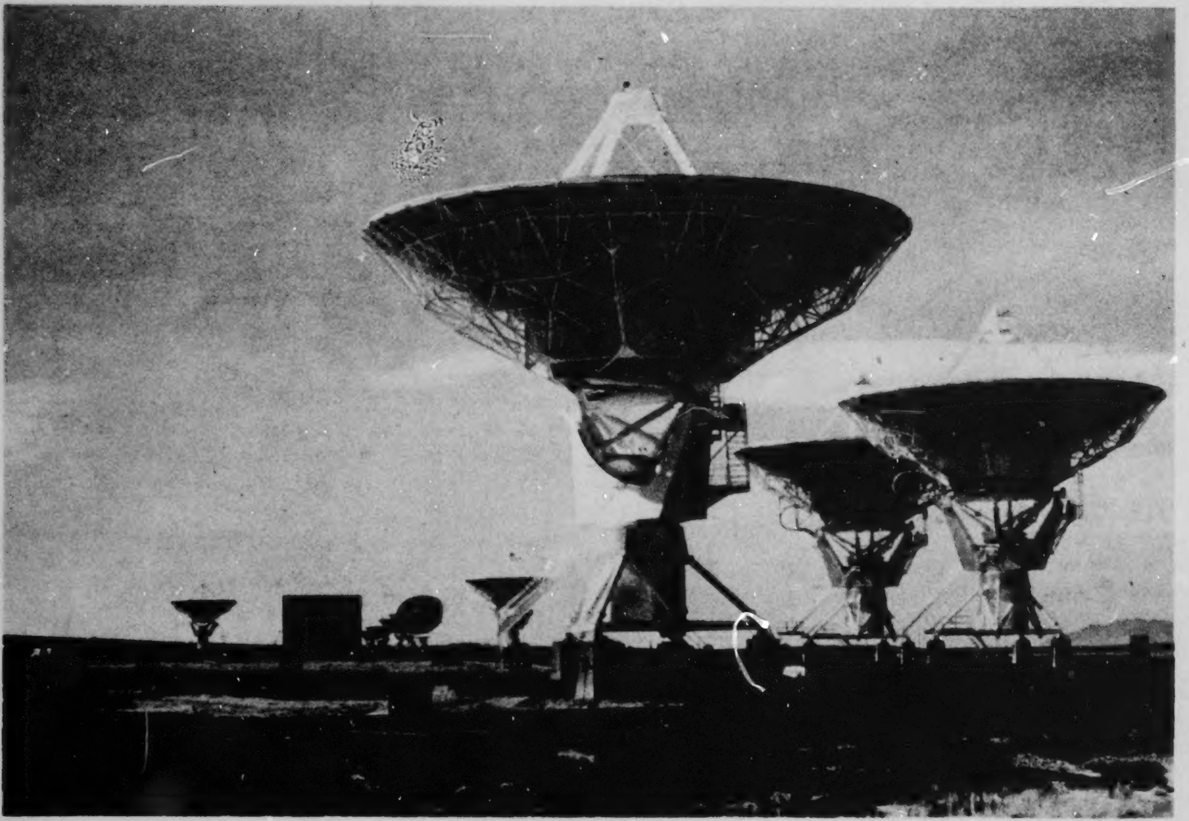
The steady increase in visitor use continued during the past year. Of the total observing time available in this period, 79 percent was used by 155 visiting scientists for research programs in radio astronomy, radar astronomy, and upper atmospheric research.

National Radio Astronomy Observatory

NRAO operates four major radio telescopes for use by the scientific community in their research in all fields of radio astronomy. Studies in millimeter-wavelength radio astronomy are made using the 11-meter telescope at Kitt Peak, near Tucson, Arizona. Observations at decimeter and meter wavelengths are made with either the 91-meter meridian transit telescope or the 43-meter fully steerable telescope, both located in Green Bank, West Virginia. At this site, harmful radio interference, so common elsewhere at these wavelengths, has been minimized by the natural shielding of the mountains and by a National Radio Quiet Zone that surrounds the site.

Studies of the very small angular scale structure of radio sources are made with the 43-meter antenna as a part of the very long baseline interferometer (VLBI) network. Maps of the distribution of radio emission from galactic sources, quasars, and radio galaxies are being obtained using the partially completed Very Large Array (VLA). Fabrication of the VLA is taking place on the Plains of San Augustin near Socorro, New Mexico, and will be completed by early 1981. NRAO is operated by Associated Universities, Inc., and has its headquarters in Charlottesville, Virginia.

During the past year construction of the VLA continued on schedule. Time devoted to scientific and test operations remained fairly constant, with an average uptime of 50 to 55 percent of the total available hours. The number of antennas in use at one time increased from 12 to 17 and will remain at or near this figure for the next year. The maximum number of baselines available increased from 66 to 136, and the longest baseline available



Very Large Array. Nearing completion of construction, the VLA radio telescope has been used increasingly for research as more of the relocatable antennas and more baseline become available. Shown here are some of the eventual 27 antennas positioned around the center of the wye-shaped railroad tracks that will extend some 19 kilometers in each of three directions.

increased from 11.5 km to 18.2 km. A contract was placed during the spring covering the Phase V construction work, which will complete all trackage for moving antennas along baselines, antenna foundations, and utilities required for the project.

Seven antennas were accepted from the vendor this year and a similar number were outfitted with feeds, subreflectors, receiving, amplification, and other equipment by NRAO personnel. A considerable effort continued to improve the reliability of the electronics, including cryogenics and parametric amplifiers. Major additions to the computer hardware and software packages were made to keep abreast of the increasing data rate and to meet continuum and mapmaking requirements.

Approximately one-third of the time on the VLA during the second half of 1979 was devoted to astronomical observations. The remainder of the time was allocated to continuing construction (40 percent) and instrumental development and tests. Of the 62 research projects receiving telescope time, 84 percent involved visitors, working either independently or in collaboration with NRAO staff.

The improved resolution and mapping capabilities of the VLA have spawned a multitude of research projects aimed at establishing spectral information for compact objects, such as quasars, galactic nuclei, and X-ray sources. In addition, the VLA has been used to map the radio brightness distributions of a number of radio galaxies and head-tail galaxies. In maps with high sensitivity and dynamic range, radio "jets," "beams," and "hot spots" are a common occurrence. The presence of distorted radio sources in clusters of galaxies helps probe the environment of the intracluster medium.

The millimeter-wave telescope on Kitt Peak has successfully detected and mapped carbon monoxide in external galaxies. Twenty-three new pulsars north of declination +20 degrees were found in a completion of the 91-meter telescope survey at Green Bank. The survey will provide information about the galactic distribution and luminosities of pulsars. A number of spectral line studies, carried out with the 43-meter Green Bank telescope, are investigating the structure and physical conditions in HII (Hydrogen) regions and supernova remnants. VLBI activity has continued to probe the nature of maser configurations in young star-forming regions as well as near evolved stars in the galaxy. Additional high resolution studies of extragalactic sources have monitored the slow expansion of the central components of several galaxies and identified new structures in many others.

A first version of the deformable subreflector for the 43-meter Green Bank antenna was found to eliminate the sidelobes, improve beam symmetry, and significantly increase the efficiency at a wavelength of 1.3 cm. A final improved version is now under construction in Green Bank so that improved short wavelength performance of the telescope can be expected next year.

A Model IV autocorrelator receiver is being developed for the 43-meter telescope. When put into operation at the end of the year it will allow simultaneous observations of several wavelengths over a bandwidth of up to 4 GHz. This will allow much greater sampling of the velocities of components of distant galaxies. The standard receiver of the 43-meter telescope is currently being improved through the development of a dual-channel upconverter mass system to cover 5-26 GHz.

In the millimeter-wave region, NRAO has begun working on a bolometer millimeter-wave detector operating at liquid helium temperatures to greatly improve continuum performance through the 1-, 2-, and 3-millimeter atmospheric windows. Improvements have also been made in the millimeter-wave cooled mixer receivers.

A newly developed package of spectral-line VLBI computer software allows data to be calibrated and phase-referenced, leading to spectral line maps of distinct objects such as quasars and centers of galaxies. Jointly with KPNO, NRAO has developed a common format for the transfer of multidimensional image data between astronomical institutions. Prospects are for this to become adopted for universal use by other observatories. During the year 317 visitors, including 40 students, used the NRAO telescopes. The visitors represented 97 institutions.

Sacramento Peak Observatory

Located at an elevation of 2,760 meters (9,055 feet) in the pine forests of the Sacramento Mountains of New Mexico, SPO offers unique facilities for studying the physics of the Sun. The Vacuum Tower Telescope presents superb solar images to an impressive array of focal plane instruments especially designed to reveal the finest details of the magnetic fields and gas flows in the Sun's atmosphere. The new low velocity facility at the Big Dome is designed to measure with unprecedented precision the large-scale flow patterns on the solar surface.

SPO operates a 1.2-meter stellar telescope at Cloudcroft under a contract between the NSF and the U.S. Air Force. This instrument is ideally suited to observe stellar analogs of solar phenomena such as flares and activity cycles. SPO is operated by the Association of Universities for Research in Astronomy, Inc., under contract with the National Science Foundation.

Several instruments brought into use during 1979 underscore the drive to study solar activity during the forthcoming solar maximum (1980-81). A white-light flare polarimeter will be used to investigate the violent heating that takes place during explosive solar flares. The "one-shot" coronagraph will search for the spectacular mass-ejection of coronal transients observed with Skylab in 1973.

The High Altitude Observatory's Stokes polarimeter and coronal emission line polarimeter located at SPO have been upgraded to provide data on photospheric and coronal magnetic fields in support of NASA's Solar Maximum Mission satellite and the international cooperative research programs planned for Solar Maximum Year.

SPO is committed to the application of the most advanced technology to astronomical instrumentation. A two-dimensional CCD optical and infrared detector array and its associated electronics was brought on-line at the Tower Telescope in 1979. Microprocessor controllers for these arrays are currently being fabricated. They will greatly increase the rate at which data can be acquired, thereby permitting greater accuracy in the measurement of the extremely small flows associated with solar oscillations and global circulation patterns. SPO has acquired three new medium-sized computers to control instruments, analyze data, process astronomical images, and perform theoretical calculations.

The facilities of SPO are available to all qualified scientists. Telescope time is allocated on the basis of scientific proposals, which are reviewed by external referees. More than 60 percent of time available on SPO telescopes is allocated to the research programs of visiting scientists.

Atmospheric Sciences

Atmospheric sciences is a derived science in which basic concepts from physics, chemistry, mathematics, and biology are applied in various ways to improve understanding of the atmosphere as well as understanding of its impact on life. With the development of the atmospheric sciences has come the realization that there are strong links with other sciences, such as astronomy, oceanography, earth sciences, biological sciences, and social sciences.

NSF's decisions to support studies in particular areas of the atmospheric sciences are influenced by related research carried out by several of the mission agencies. The NSF programs complement mission agency goals, and NSF maintains strong liaison with mission agency counterparts.

NSF funds more than half the basic research in atmospheric sciences conducted at U.S. universities. This support is provided through the aeronomy, atmospheric chemistry, climate dynamics, experimental meteorology, meteorology, and solar terrestrial programs plus the Global Atmospheric Research Program (GARP). Facilities for research are made available by the National Center for Atmospheric Research.

Aeronomy is concerned with the nature of the atmosphere at altitudes where solar radiation and energy are capable of altering the electronic bonds of constituent atoms, molecules, and ions.

Atmospheric chemistry involves laboratory, field, and modeling efforts on the natural cycles of constituents and trace substances, both gaseous and particulate, and the effects of human activities on these cycles.

The climate dynamics program attempts to develop a basis for predicting climate variations through climate data assembly and through analysis, modeling, and assessment of the impact of those variations on human affairs.

Experimental meteorology and weather modification emphasizes the experimental, field-oriented investigation of mesoscale meteorology on which regional weather occurs and also includes cloud microphysics studies.

The meteorology program involves research on the dynamics and physics of the lower atmosphere.

Solar terrestrial research is concerned with the release of energy by the Sun, its propagation through the interplanetary medium and the atmosphere, and its eventual impact on the upper atmosphere.

The Global Atmospheric Research Program (GARP) is an international study of the physical processes that affect the varying large-scale characteristics of the lower 30 kilometers of the atmosphere. The effort is planned jointly by the World Meteorological Organization and the International Council of Scientific Unions. NSF is the lead agency for supporting the academic and nonprofit research community participation in GARP. Current emphasis is on the Global Weather Experiment and a concurrent regional subprogram known as the Monsoon Experiment.

The National Center for Atmospheric Research (NCAR), located in Boulder, Colorado, conducts long-term cooperative research with universities and other agencies on selected problems of national and international importance and scope. Research at NCAR is aimed at extending the ability to model large-scale atmospheric phenomena; understanding climate; improving understanding of severe local storms; determining the chemistry of the atmosphere and the effects of human activity on air quality; and examining the solar atmosphere and its influences on the region between the Sun and the Earth, as well as the weather and climate affecting man's activities.

NCAR also provides the atmospheric research community with computer, aircraft, balloon launch, radar, and instrument development facilities that could not be maintained by an individual institution or university. NCAR and the National Scientific Balloon Facility are operated under contract to NSF by the University Corporation for Atmospheric Research, a consortium of 48 member universities in the United States and Canada.

Plasma Convection in the Upper Atmosphere

Although the near-earth magnetic field has a simple dipole or bar-magnet character, its more distant structure is severely distorted by interaction with hot solar plasma (ionized gas) that continuously blows out from the Sun. The outer reaches of the Earth's magnetic field cause a "magnetospheric" cavity in this "solar wind" some tens of earth radii across and stretching away from the Sun past the distance of the Moon's orbit.

Charged particles with a broad range of energies are trapped within, or confined to move along, tubes or shells of earth magnetic field lines in this magnetospheric cavity. Energetic electrons and protons that periodically dump out of the magnetosphere along high latitude field lines into the Earth's upper atmosphere can cause aurora, radio blackouts, occasional associated power line surges, rare ozone depletions, and a variety of other effects.

This environment is sufficiently complex that observational programs continue to be a driving factor in developing understanding of the processes determining its nature. These observations take advantage of the fact that many processes occurring in the outer reaches of the magnetosphere map back to Earth along magnetic field lines which, owing to their geometry, converge as they approach Earth. This spatial focusing and consequent concentration of magnetospheric boundaries permits many effects associated with very extended regions of the magnetosphere to be sampled in narrow latitudinal intervals in the relatively nearby 100- to 500-kilometer "ionospheric" altitude region of the upper atmosphere.

An important case is the motion, in the high-latitude ionosphere, of the feet of magnetic field lines that trace to great distances into the magnetosphere. If one could sit above the Earth on the foot of such an auroral-region field line, starting at either dawn or dusk, one would move approximately along a latitude arc towards the Sun and then, upon approaching noon, be carried across the pole towards the midnight sector. Then one would continue along a latitude arc back towards the starting point. Plasma tracing these trajectories can move at speeds of kilometers per second, corresponding to driving electric fields tens of kilovolts across the dawn-dusk ionospheric polar cap.

A qualitatively new capability is now available to measure plasma velocities (and derived electric fields) continuously in time over the entire band from 60 to 75 degrees magnetic latitude. This has been accomplished by the addition of a 46-meter-diameter fully steerable antenna

AURORAL OVAL
AN FRANCISCO
DALLAS
ORT WORTH

Studying the upper atmosphere. The new 46-meter fully steerable radar antenna at Millstone Hill, Massachusetts, is seen behind the older, fixed, vertically pointing 67-meter antenna. The instruments are used for studying the sources and dynamics of magnetospheric phenomena, the best known of which is the spectacular aurora circling the polar regions, shown in this satellite picture.

to the Millstone Hill radar, Westford, Massachusetts. Data collected to date with this newly upgraded facility are already extending the understanding of both solar control and atmospheric effects of these circulation patterns. Magnetically quiet days have been found to have a plasma flow pattern consistent with expectations from present idealized models, while increasingly disturbed days show subtle to dramatic departures from this pattern.

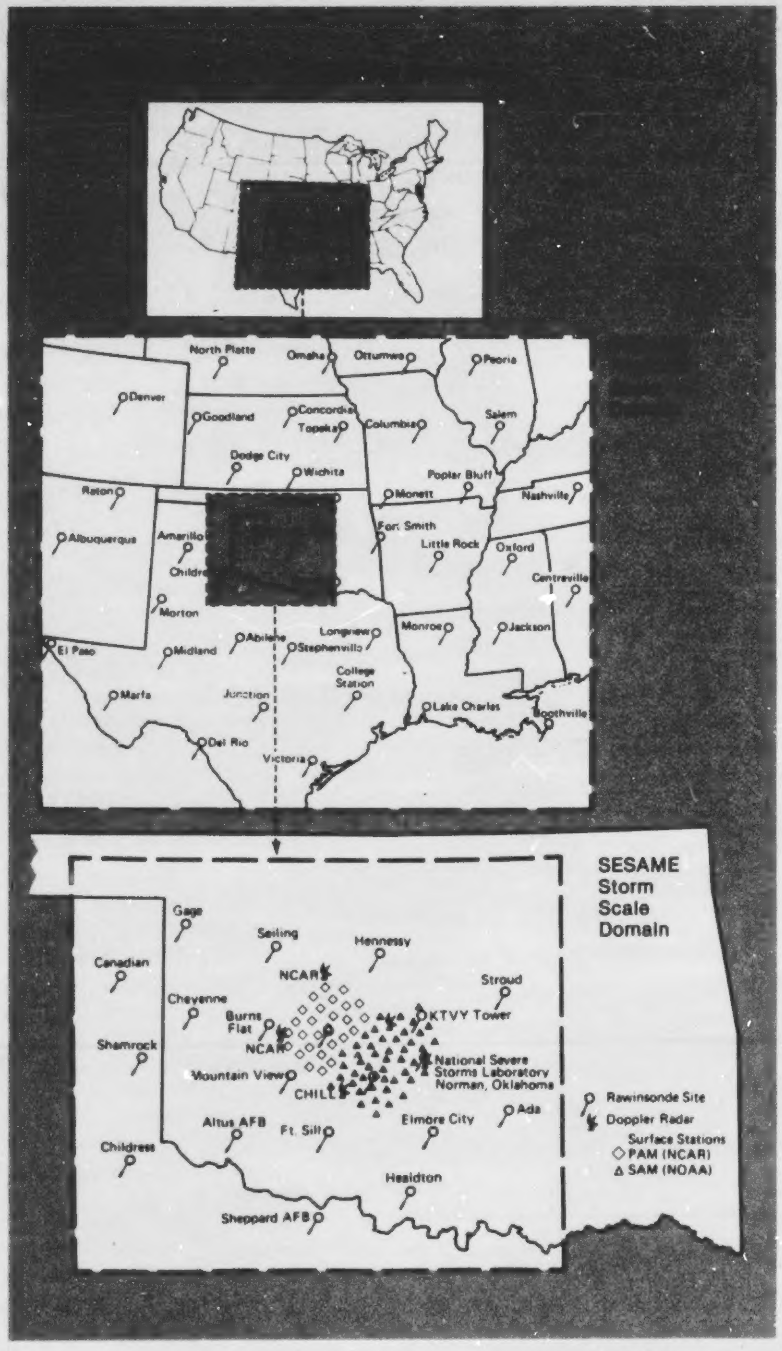
SESAME 1979

Project SESAME (Severe Environmental Storms and Mesoscale Experiment) is a continuing national cooperative experiment to lay the foundation for improved prediction of severe convective storms. More broadly speaking, SESAME seeks to improve the scientific understanding of mesoscale weather. Weather events on this scale—a horizontal distance of from 10 to 1,000 kilometers—are among the most intense and most difficult to predict. Timely and accurate forecasts and warnings of tornadoes and other disastrous local events, such as extreme winds, flash floods, and hail would contribute greatly to the saving of life and reduction of property damage.

NSF cooperated with the National Oceanic and Atmospheric Administration, the National Aeronautics and Space Administration, and other Government agencies in the basic support of SESAME 1979, a field observational program conducted during April-June 1979. From an operations base in Norman, Oklahoma, SESAME 1979 observations extended over most of the central United States.

During April emphasis was given to observations to provide several data sets for the testing of regional-scale prediction models. On these case-study days an augmented rawinsonde (radar wind measurement) network (16 supplemental observing sites), covering an area of 1,800-kilometers square, provided soundings at 3-hour intervals. These select days were also supported by intensive observations (at 3-minute intervals) from meteorological satellites.

The regional-scale data collection began on April 10, the date of a disastrous tornado outbreak in Texas and Oklahoma. The observations collected by the rawinsonde network, meteorological satellites, and multiple Doppler radar net-


North Platte
Omaha
Ottumwa
Peoria
Denver
Goodland
Concordia
Topeka
Columbia
Salem
Dodge City
Wichita
Poplar Bluff
Monett
Nashville
Raton
Albuquerque
Amarillo
Fort Smith
Little Rock
Oxford
Centreville
Morton
Monroe
Jackson
Longview
El Paso
Midland
Abilene
Stephenville
College Station
Marfa
Junction
Lake Charles
Boothville
Del Rio
Victoria
SESAME Storm Scale Domain
Gage
Seiling
Hennessy
Canadian
NCAR
Stroud
Cheyenne
Burns Flat
KTVY Tower
Shamrock
NCAR
National Severe Storms Laboratory Norman, Oklahoma
Mountain View
CHILL
Altus AFB
Ft. Sill
Elmore City
Ada
Childress
Healdton
Sheppard AFB
Rawinsonde Site
Doppler Radar
Surface Stations
◇ PAM (NCAR)
△ SAM (NOAA)

Weather stations. This network of observing sites supported a 1979 field experiment to understand the dynamics of severe storms. Intensive data collection in the Oklahoma-Texas area was supplemented by regional surface stations, aircraft, and satellites.

work will provide an unprecedented data set for wide application in modeling and forecasting studies. During May-June, rawinsonde sites were relocated into a 400-kilometer-square area of Oklahoma and Texas to support investigations of individual storm-scale phenomena; these studies drew on data collected by a network of 7 Doppler radars, a dense network of 80 surface stations, and 10 research airplanes.

John McCarthy at the University of Oklahoma employed research aircraft and radars in experiments to determine how mid-level environmental air is brought into convective storms and what its role is in forming the downdraft. The downdraft appears to be a critical element in storm propagation and new development, and intense downdrafts sometimes result in wind damage and are a serious aviation hazard. However, there are differing theories as to whether the air that produces downdrafts enters the storm at high levels or at mid-storm levels.

An instrumented T-28 airplane, specially armor-plated and stressed to withstand hail and severe turbulence, was used by South Dakota School of Mines and Technology and NCAR researchers to study the interior of convective storms and to determine interactions between the storm and its environment. The airplane carried instruments for measuring precipitation particles, and data collected by this system will contribute to the understanding of the initiation and growth of precipitation in convective clouds and of the interaction between precipitation particles and air motion in convective storms. Simulations of these processes in convective storm models, when tested against the observations, will help develop the understanding of how severe weather phenomena, such as tornadoes, hail, and lightning, are produced.

Thomas Seliga of Ohio State University combined the observing capabilities of the T-28 with the polarization capabilities of the CHILL (University of Chicago-Illinois State Water Survey) radar and a National Severe Storms Laboratory vertically pointing Doppler radar to test a unique scheme for rainfall estimation. The new radar technique determines both the size and number of falling raindrops from measurements of radar reflectivity both along and perpendicular to the radar beam.

Winds at high altitude. The MST radar array in Fairbanks, Alaska, can rapidly detect actual air motions high above the site. This is an advance over existing balloon or rocket samplers for a variety of atmospheric studies.

Coupled with previous laboratory measurements of the shape of falling raindrops and the theory of how radar waves are scattered by them, these radar data permit rainfall amounts to be computed. Comparisons between computed and measured amounts are good. The measurements of rainfall using this new technique, if widely implemented, could provide crucial estimates of heavy rainfall during severe storms which frequently lead to flash floods.

The initiation and preferential occurrence of severe storms is believed to be significantly affected by the planetary boundary layer. Scientists at Oregon State University, the University of Virginia, and NCAR cooperated in a planetary boundary-level experiment within SESAME 1979 to investigate the influence of the nocturnal boundary layer and the accompanying low-level jet stream on the initiation of convective storms. Special flights by instrumented aircraft, a tethered balloon system, and an acoustic sounder provided the basic measurements during an intensive 2-week observational program.

SESAME 1979 is a start toward a national program of research on mesoscale meteorological phenomena ranging in size from mid-latitude cyclones to tornadoes and urban-scale perturbations on the weather. Recent NSF-sponsored workshops have explored the research needs and opportunities in this field.

The MST (Mesosphere-Stratosphere-Troposphere) Radar

An experimental radar, designed to provide new knowledge of winds, turbulence, and waves in the atmosphere between about one and 100 kilometers, is being constructed in Fairbanks, Alaska. The radar transmits a 50-megahertz signal at a peak power of 6.4 megawatts from a phased dipole array of 40,000 square meters. To a layman's eye, the apparatus resembles a vineyard before planting.

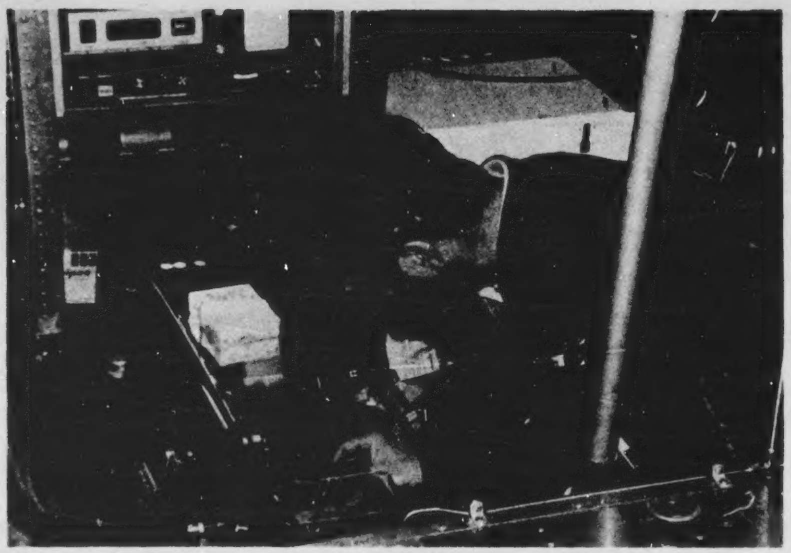
The device measures the downward scattered radiation arising from variations in the radio refractive index; at the highest elevations, the returned scattered radiation arises from free electrons. The scattered radiation, when suitably processed, can be used to infer air motions along the local vertical, and this can be done about every 4 minutes. Conventional balloon techniques, by contrast, permit such measurements only twice a day, while rockets are even less frequent.

Thus, the motion of the atmosphere can be measured in much greater detail and should provide new information for regions of the atmosphere rarely probed at all, or much less frequently than is currently possible using conventional equipment. Such information is vital for an understanding of weather systems, atmospheric composition and chemistry, radio propagation, and atmospheric wave motions. The facility is being constructed by scientists from NOAA's Aeronomy Laboratory in Boulder, Colorado, with partial support from NSF.

MONEX—The Field Observation Year

The year-long observational phase of the Monsoon Experiment (MONEX) began on December 1, 1978. MONEX, a major international experiment to increase understanding of atmospheric and oceanic processes associated with the monsoon, is a regional subprogram of the Global Atmospheric Research Program (GARP) and is taking place concurrently with the GARP Global Weather Experiment.

Over 20 nations participated in MONEX, with the United States, India, and the U.S.S.R. providing the major share of special observational platforms. NSF, with lead agency responsibility for U.S. participation in MONEX, established the U.S. MONEX project office at the National Center for Atmospheric Research. The U.S. field program included three research aircraft, three research ships, special satellite programs, and portable



Monsoon studies. Anthony Delany calibrates a spectrometer aboard NCAR's Electra aircraft as part of the winter phase of the 1979 MONEX. The laser instrument identifies the sizes and types of particles suspended in the air, information used in trying to understand the relationship of monsoons to global weather.

radar, surface, and upper air observational platforms. Approximately 200 U.S. scientists, technicians, and support personnel from about 25 universities were involved.

The monsoon is the most energetic regional circulation in the Earth's atmosphere. Because of its tremendous influence on the agriculture, economy, politics, and health of a major portion of the world's population, the forecast of the onset and breaks of the monsoon is probably mankind's most important single prediction. Also, because of its size and high energy level, the monsoon circulation affects weather and climate on a global scale. MONEX, the most complete scientific effort of its kind to date, has the potential, therefore, for important advances in atmospheric sciences.

The monsoon circulation has two distinct phases in Asia. In the winter, there is a dominant north-east wind from the Chinese land mass across the South China Sea. This circulation, known as the winter monsoon, leads to surges of cold air streaming towards the Equator, causing intense rains over much of Southeast Asia. To investigate the winter monsoon and its associated phenomena, an extensive observational program was established for the period December 1978 through February 1979, with operations centered at Kuala Lumpur, Malaysia. The United States sent about 60 scientists and technicians to Winter MONEX, primarily during December 1978 when two U.S. research aircraft were used for intensive observations. Because of the successful aircraft, satellite, and radar observational programs, it is anticipated that high-quality winter monsoon research will result.

During the period May through July 1979, approximately 150 U.S. scientists and technicians utilized three research aircraft, three research vessels, and a U.S. geostationary satellite positioned over the Indian Ocean to obtain data on the summer monsoon. This is the southwest wind system that surges across the Indian subcontinent, bringing sorely needed rain to hundreds of millions of people.

The U.S. effort for Summer MONEX began with a 2-week operation during May that was centered in Saudi Arabia to gather data on the development of heat sources over the Arabian peninsula and the northern Arabian Sea prior to the onset of the monsoon. For the last 2 weeks of May and all of June, primary Summer MONEX operations were directed from a center established at Bombay, India. During that period, extensive observations were obtained using the aircraft over the Arabian Sea as the monsoon developed and spread over southern India.

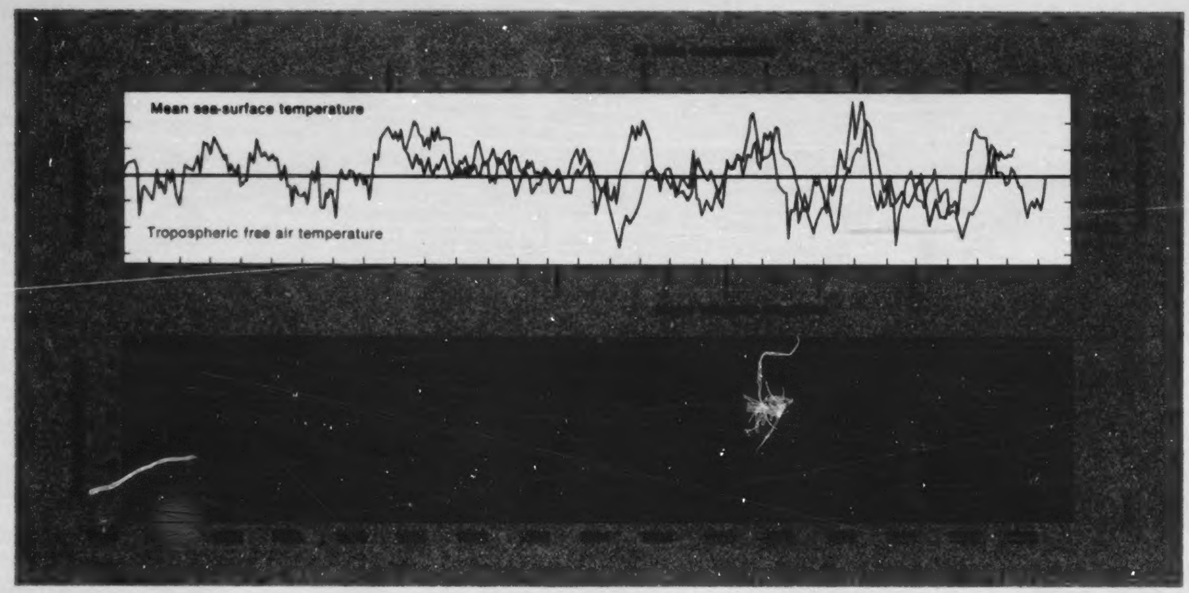
During July, the operations center was shifted to Calcutta. At that time, data were gathered from two large disturbances that developed over the Bay of Bengal. These monsoon disturbances traditionally provide most of the rain that falls on India during the monsoon. Since the development of the summer monsoon and its associated disturbances is not well understood, the unique data set obtained for MONEX should greatly extend knowledge of these phenomena. The processing of the MONEX data sets is underway now.

An important factor in the success of MONEX was the excellent international cooperation and support that developed between scientists and governments. A close working relationship among the scientists was realized at each of the operations centers. The major partners in MONEX were Malaysia, India, the United States, and the U.S.S.R.; other prominent participants were the People's Republic of China, Hong Kong, Indonesia, Saudi Arabia, Somalia, and Australia.

Climate Variability

There is no comprehensive model that can explain the causes of climate variability and climatic change. Significant progress is, however, being made in identifying important links between atmospheric and oceanic processes. These links, in turn, provide important insight into the causes of climate variability and, in some cases, may provide a means of predicting climatic changes.

Reginald Newell and his students at



Long-term relationships. The Southern Oscillation Index (SOI), a standard measure of air pressure differences between two points in the South Pacific, appears to presage by several months an increase in equatorial ocean temperature, which in turn anticipates a later rise in air temperature (seasonal variations have been removed from these records). The SOI also shows a relationship, with a six-month lag, to Northern Hemisphere air temperatures (and may provide a way to forecast seasonal weather), as well as to the "El Niño" events that disrupt southern Pacific fisheries.

the Massachusetts Institute of Technology have assembled and analyzed a global data set of monthly sea and air temperatures covering the period 1949 to present. Their analysis of these data has revealed an important link between changes in the equatorial Pacific sea-surface temperature and changes in the overlying atmospheric pressure and wind pattern.

A measure of these changes is the southern oscillation index (SOI), which is defined as the pressure differences between Darwin, Australia (12°S, 131°E), and Easter Island (27°S, 109°W). Changes in the SOI correlate with and precede changes in the ocean temperature. Nearly half of the variance in ocean temperature can in fact be correlated with changes in the SOI.

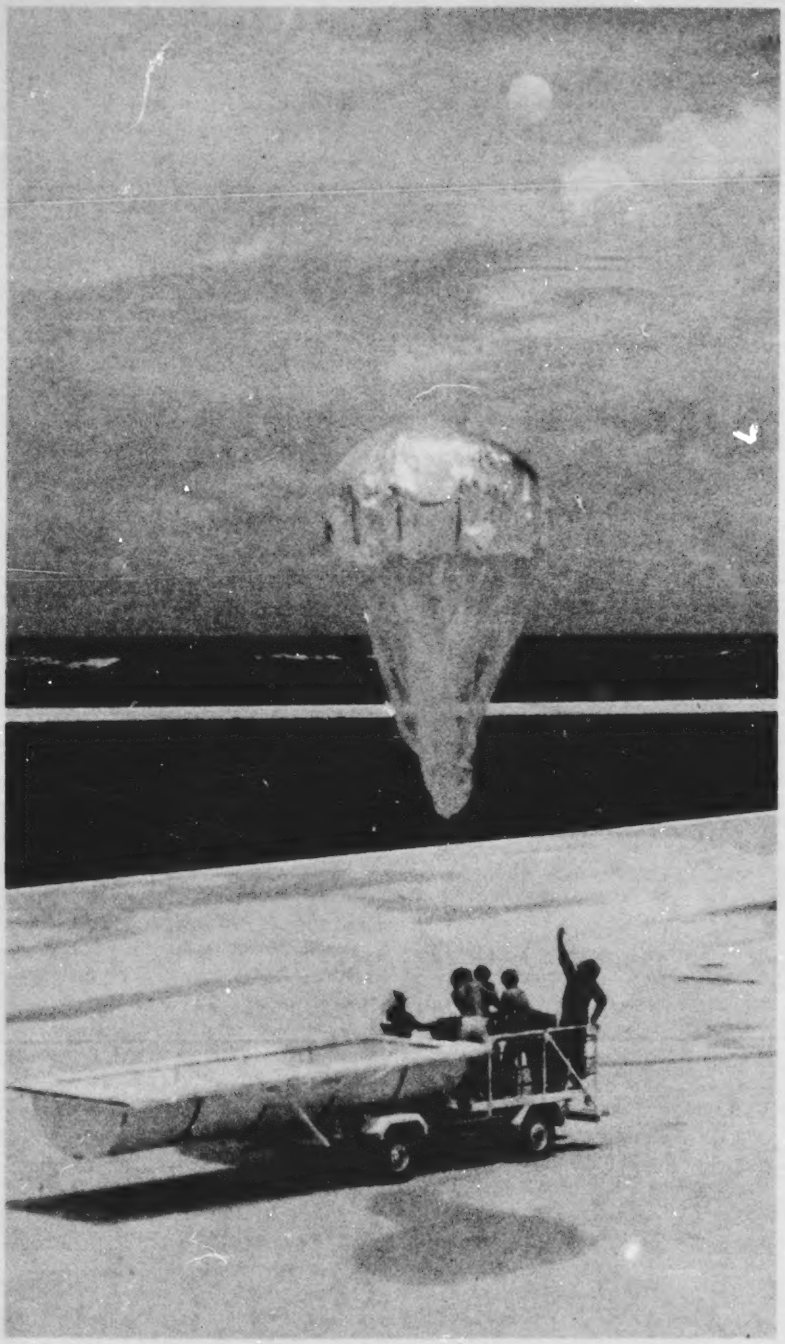
It is hypothesized that the pressure changes in the atmosphere influence tropical winds that in turn influence sea surface temperatures (via upwelling). Sea temperatures then influence air temperatures via overall heat transfer. It was also discovered that changes in air temperatures in the Northern Hemisphere higher-latitude zones (temperatures averaged over several degrees of latitude) can be related to changes in tropical air temperatures some 6 months before.

Additionally, the SOI can be related to variations in the amount of rainfall over a wide area of the equatorial Pacific. Heavy rainfall coupled with unusually warm sea-surface temperatures, which occurs every half-dozen years or so along the normally cool and dry coast of Peru and is known as "El Niño," is a local manifestation of weak trade winds, anomalously warm sea-surface temperatures, and heavier than normal rainfall in the entire equatorial Pacific area.

The relationship between the SOI, "El Niño," the hydrologic cycle, and Pacific trade wind variations are also being studied by Elmar Reiter of Colorado State University. Reiter has further detected a marked quasi-biennial oscillation in tropical Atlantic trade wind convergence which appears to be related to a similar oscillation in equatorial stratospheric winds and to rainfall fluctuations in northeastern Brazil. These and other results were presented at a U.S.-U.S.S.R. Conference on Climatic Change in Tiblisi, U.S.S.R., in October 1979. The recent studies emphasize the important role of the tropics in regulating global climate.

National Center for Atmospheric Research

During 1979 the National Center for Atmospheric Research was involved in the deployment of two unique research platforms—aircraft dropwindsondes and constant-level balloons—over the tropical regions during the Global Weather Experiment (GWE), conducted under the auspices of the Global Atmospheric Research Program (GARP). These research platforms are the result of a multi-year development by NCAR. The experiment's goals are to gather comprehensive global



Tropical launch. A constant-level balloon is sent aloft during the observing phase of the Global Weather Experiment. These balloons measured wind and temperature for several weeks at altitudes of 19 kilometers.

data, especially from data-sparse areas such as the Southern Hemisphere and polar regions, needed to improve the quality of atmospheric prediction models and to determine the fundamental predictability of the atmosphere. Specially equipped ships, instrumented aircraft, balloons, buoys, and satellites were dedicated by many nations to the GWE, which ran through 1979.

The NCAR-developed observing systems were designed to obtain meteorological data in the equatorial regions between 20°N and 30°S, thereby augmenting the existing operational and space-based components of the World Meteorological Organization's World Weather Watch. Dropwindsonde operations were conducted using aircraft operating from Ascension Island (in the equatorial Atlantic), Panama, Acapulco, Diego Garcia (an island in the Indian Ocean), and Hawaii. The sondes radioed temperature, pressure, humidity, and wind data back to the aircraft as they were dropped from altitudes of 10,700 and 12,200 meters.

NCAR staff launched tropical constant-level balloons from Ascension Island, Canton Island (in the equatorial Pacific), and Guam to measure wind and temperature data for levels above the aircraft during the GWE. The balloons floated at a constant altitude of about 19 kilometers for several weeks. Wind information was obtained during overpasses of TIROS (television infrared observation satellite). In addition to the wind data, the balloons transmitted data on air temperature, vertical motion during the day, and infrared radiation at night. Data from the dropwindsonde and balloon systems are being processed at NCAR.

NCAR also managed U.S. participation in the regional GWE subexperiment called MONEX (Monsoon Experiment) that took place in India and adjacent areas during late 1978 and 1979. That processed data will be archived at the Space-Based Observing Systems Data Center in Stockholm for use by atmospheric researchers around the world.

NCAR scientists, along with scientists from seven universities, last year embarked on the Acid Precipitation Experiment (APEX) to study a problem of increasing environmental concern. Acid rain results mostly from the burning of fossil fuels by electric utilities, the smelting of metallic ores, effluent from petroleum refineries, and emissions from automobiles. According to the National Academy of Sciences, acid precipitation currently causes $200 million in damage to U.S. forests and orchards each year. Because of their high acidity, more than half of the lakes in the Adirondack Mountains of New York are now devoid of fish. It is believed that the acidity is derived largely from pollutants released in industrial areas of the Midwest, particularly the Ohio River Valley.

APEX is the first project to measure all the important acids and acid precursors simultaneously in the atmosphere to provide an understanding of the phenomenon of acid rain, and will therefore assist in identifying options for responding to the problem. The objectives of APEX are: (1) to survey the distribution of acidic and basic compounds in the atmosphere and their variability with season and meteorological conditions; (2) to relate quantitatively the concentrations of acids in air to their occurrence in cloud water and rain water; (3) to investigate the chemical processes controlling atmospheric acidity; and (4) to determine the relative importance of in-cloud scavenging processes for acids in rain.

Two field missions have been conducted using the instrumented NCAR Queen Air aircraft and a mobile ground unit. Measurements were taken between Denver, Colorado, and the Atlantic Ocean, concentrating on the Ohio River Valley (an area containing many power plants) and several areas in upstate New York, including Whiteface Mountain in the Adirondacks. In a typical spring weather pattern, warm air from the Gulf of Mexico flows north and rises over a wedge of cooler air in the Northeast, where it forms clouds and precipitation.

During the spring mission, the APEX scientists compared the chemical composition of the warm, overriding gulf air with the composition of the cloud water condensing out of it and also sampled the cold air at lower altitudes for comparison with the rain water falling through it. They found that the total acidity in the air could potentially make cloud water and rain water 10 times more acidic than is actually observed. Results from this mission suggest that only a small percentage of airborne sulfur dioxide and nitrogen dioxide reacts in the cloud to produce acid, and that cloud water acidity is derived mainly from nitric acid vapor and sulfuric acid aerosol already present.

In the typical midwestern frontal storms studied, the air flowing into the cloud was relatively clean air from the Gulf of Mexico. The cold air below had picked up contaminants from midwestern industrial areas. In four frontal storms, it was found that, on the average, 72 percent of the acid in the rain was scavenged below the cloud. Future studies will also include convective storms (such as summertime thunderstorms), in which the air feeding the cloud is from the layer near the surface and cloud water may be much more acidic.

With the data collected so far, it appears possible to quantitatively relate acid concentration in cloud water and rain water to the concentrations of the acids and bases in the atmosphere, at least in the case of frontal storms. This might lead to the capability to predict the effect of polluting factors on acid rain and considerably simplify the investigation of acid rain.

A stalled high-pressure system covered the eastern United States for several weeks during the first APEX mission, which took place in the fall of 1978. Air trajectory calculations showed that air at Whiteface Mountain in the Adirondacks had originated in the Ohio River Valley. The concentration of sulfuric acid aerosol was considerably higher in the Whiteface Mountain region than in the Ohio River Valley, suggesting that during the time air travels to the Adirondacks a significant conversion of sulfur dioxide to sulfuric acid aerosol takes place.

Earth Sciences

The history of any science is punctuated by periods of rapid advance separated by times of relative stability and consolidation of ideas. Almost without exception the rapid advances are the result of a simplifying theory that unifies thinking and provides a new framework for the interpretation of observational and experimental data. When the new theory is so far reaching as to affect the whole field, scientists commonly speak of the consequences as a revolution in that field of science. And a revolution in one field of science inevitably opens new vistas and opportunities in related fields as well.

During the past decade geology has undergone such a major revolution, the second during its long history. The first occurred during the late 18th and early 19th centuries and was occasioned by the development of Hutton's principle of *uniformitarianism*. Commonly stated as the "present is the key to the past," that principle maintains that the features seen on Earth today have originated by processes that are also operating today.

The modern revolution in geology has been abbreviated into terms such as seafloor spreading, global tectonics, and plate tectonics, the last attracting the largest following. But by whatever name it is called, it has provided earth scientists for the first time with a unifying concept of global structure and composition, a new framework in which to set detailed geological studies.

Much of the research in the earth sciences today therefore contributes to the testing and evaluation of the new hypothesis. For example, study of a granite intrusion no longer involves just determining the composition and mineralogy of the rock, but will also attempt to relate it to the movement of the crustal plates and the formation of molten magmas in general. Other research, not related directly to plate tectonics, concerns processes such as erosion and weathering, and phenomena that cause or are byproducts of natural disasters. Still other projects focus on the Earth's long history and evolution.

The Foundation supports research projects in the general areas of geology, geochemistry, and geophysics. In addition, it manages the Ocean Sediment Coring Program, of which the Deep Sea Drilling Project is the main part.

New Techniques for Paleontology

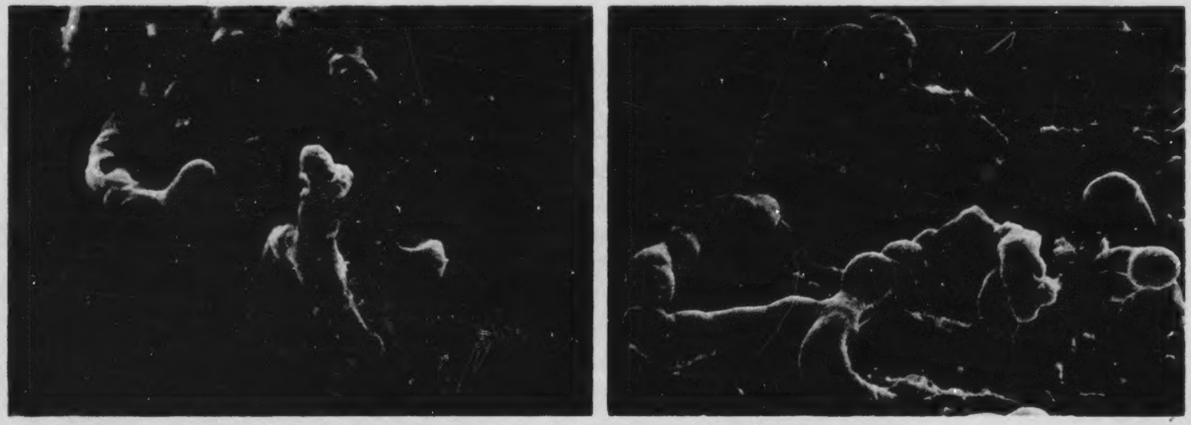
Recent research supported by the geology program has shown that certain poorly known algae and fungi have important geological applications. These relatively obscure and unstudied marine forms bore into calcium carbonate shells—which are eventually consolidated into limestones—and are major destroyers of invertebrate shells on the sea floor. Normally the organism itself is not preserved; only the tiny boreholes bear witness to their former presence. In many cases these holes are exceptionally small and are quite difficult to study. However, a technique developed by Stjepko Golubic and coworkers at Boston University overcomes these difficulties. A synthetic resin completely fills even the smallest holes left by the borers, and the resin castings then become exact external replicas of the former algae and fungi. After the encasing rock is dissolved the resin castings are studied by scanning electron microscopy. The procedure is effective on rocks containing small samples of shelly debris, specimens that are not normally useful in paleontological studies.

By comparing the casts to modern forms, scientists have a new tool for estimating the ocean depths at which the associated sedimentary rock was formed. The borers have been identified from a number of deep-sea cores as well as more shallow environments. Work is continuing to evaluate depth zones of modern forms and the degree to which particular organisms select specific kinds of shells to bore into. Considerable taxonomic work is needed on both recent and fossil forms to determine evolutionary trends and to interpret environmental significance of the various types.

The fossil forms range in age from the Ordovician Period (500 million years ago) to the present day. Evolutionary rates, however, appear to be slow, and some Ordovician forms appear to be the same as living ones. The ultimate goal of this research is to establish a comprehensive and reliable paleobathymetric model based on fossil records of algae and fungi that can be applied to many problems.

Fine Structure of the Crust and Upper Mantle

Seismic reflection profiling of the Earth's crust and upper mantle continues to have spectacular results. *The NSF Annual Report* for 1977 reported on the contributions of the Consortium for Continental Reflection Profiling (COCORP) project to the solution of two important and hitherto unresolved geological problems—the structure under the Rio Grande Rift in New Mexico, and the mode of uplift in the Wind River Uplift area of Wyoming. (The Consortium consists of five universities—Cornell, Princeton, Wisconsin, Texas at Austin, and Houston, with



Old and new. The newly developed ability to make castings of microscopic oceanic algae and fungi that bore into shells gives paleontologists a tool for determining the depths at which the host animals lived and were cemented into limestones. The casting of a 450-million-year-old animal (left) is strikingly similar to a modern one (right), which suggests that they lived in similar environmental ranges. (The organisms are only some 0.02 millimeter long.)

88°
78°
37°
37°
KY.
VA.
TN.
N.C.
S.C.
ALA.
GA.
32°
32°
88°
78°

COCORP traverse. Seismic studies of deep crustal rocks along a series of lines in the southern Appalachians have revealed large, previously unconfirmed faults that thrust crystalline rocks over younger sediments. Prospecting in these buried sediments may turn up new mineral resources.

Cornell designated as the operating institution.)

During the past year, the first during which COCORP operated a field crew full time, some 850 kilometers of line were surveyed in a variety of terrains and in exploration of four distinctly different geological problems—in the southern Appalachians, Oklahoma, Minnesota, and Wyoming.

The Appalachian study may be COCORP's most important to date. Profilings in Georgia, North Carolina, and Tennessee, when correlated with geological data, indicate that a large, thin plate of older crystalline rocks of the Piedmont province has been thrust onto and over a Paleozoic continental margin of the proto-

Atlantic for at least 250 kilometers.

The seismic data are thus consistent with a tectonic model first put forward by R. D. Hatcher of Florida State University. Thrust faults having such great horizontal displacement had been thought to be improbable or impossible because the rocks of the overlying plate would not be strong enough to hold together. The new data contradict this and support the view that large-scale, thin, crystalline thrust sheets may be significant features of many orogenic (mountain-building) zones.

The Appalachian study may have important economic fallout too. The profiling demonstrates that buried sediments underlie much of the Piedmont. Whether hydrocarbons are present in producible quantities is admittedly a moot question without further data, but the discovery of these sediments calls for reconsideration of the oil and gas possibilities of the southern Appalachians.

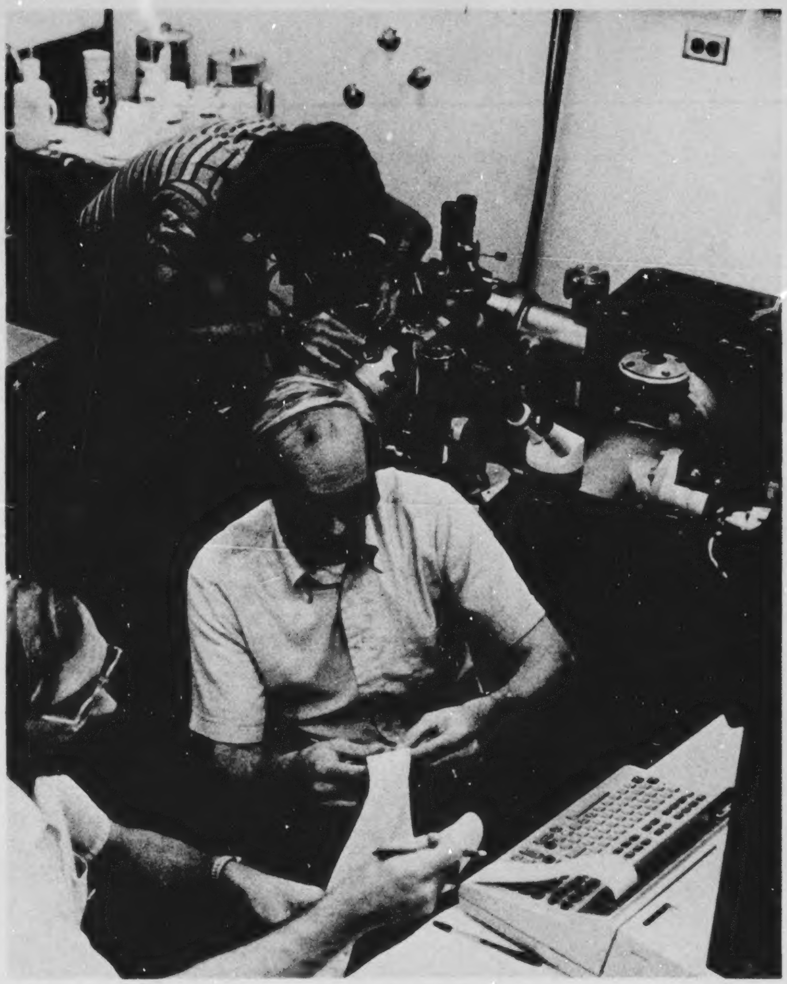
Mensuration and Instrumentation

The past two decades have brought incredible advances in the ability to detect and measure trace amounts of materials. Elements that could not be detected in concentrations of parts per million a few years ago can today be measured precisely in parts per billion. Similarly, such devices such as electron probes and high-pressure instruments allow detailed study and analysis of natural materials under conditions such as must exist within the Earth.

Much of the recent growth of geochemistry has been inspired and realized by these advances in instrumentation. In few areas is the dependence of science upon technology more apparent than at the forefront of geochemistry where new instruments and techniques achieve results that, until recently, were impossible. Spectacular examples of the new tools of geochemistry are ion microprobe analyzers, transmission electron microscopes, and diamond-cell high-pressure cells. Providing these and other innovative instruments to geochemists is a major objective of NSF's geochemistry and petrology programs.

Broad topics of current interest to geochemists are the behavior of fluids in the crust, the nature and timing of orogenic and metamorphic events, and chemical heterogeneities in the mantle. Interest is also strong in studies of kinetic phenomena such as diffusion and crystal nucleation, growth, and dissolution. Diffusion and other experimental studies were greatly facilitated when scientists at the Massachusetts Institute of Technology achieved the first synthesis of large, gem-quality diopside crystals. These crystals, which represent an important mineral in the mantle, have many experimental applications.

Elsewhere, experimental studies of crystal growth rates were measured using microscope heating stages at temperatures



Sophisticated tools. Researchers use an ion microprobe at the Massachusetts Institute of Technology for trace-element and isotopic analyses on minute parts of rocks. Such studies enable earth scientists to understand the deep-earth conditions under which rocks form.

up to 1,600°C. Growth rates have also been measured in programmed cooling rate experiments. Similarly, dissolution and melting studies have been undertaken. All of these studies provide data that elucidate the chemical mechanisms of igneous processes.

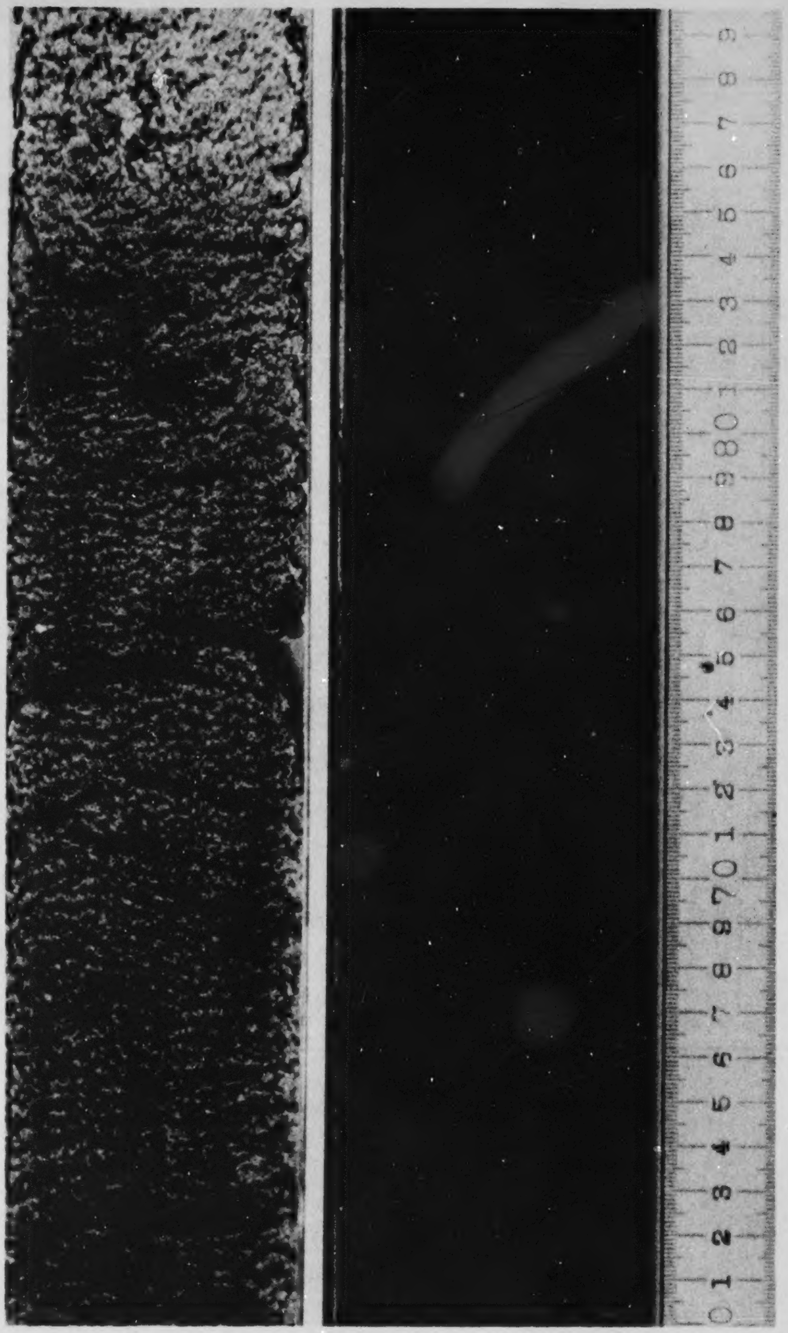
The experimental studies described above, like many aspects of geochemical research, have direct relevance to problems of common concern. Understanding kinetic phenomena is fundamental to understanding the formation of many ore deposits, the behavior of toxic wastes in the environment, the migration of hydrocarbons and aqueous fluids in the crust, and even the prediction of catastrophic events such as volcanic eruptions and earthquakes.

Ocean Sediment Coring Program

The Deep Sea Drilling Project (DSDP), funded by NSF since 1966, is the major effort of this program; its fundamental objective is the exploration of the Earth's surface beneath the ocean. DSDP operates principally by recovering sediments and rocks using deep drilling and coring techniques. Joint Oceanographic Institutions, Inc., a nonprofit corporation with members from among the major oceanographic research institutions, provides the scientific planning for the project; Scripps Institution of Oceanography has prime responsibility for the operations of the program; and Global Marine, Inc., performs the actual drilling and coring operations using its drilling ship, the D/V *Glomar Challenger*, under subcontract to Scripps.

DSDP began operating in August 1968. By mid-September 1979, the *Challenger* had drilled nearly 800 holes at 503 sites in a series of 68 cruises (legs), which generally lasted 2 months, covering every major ocean basin except the Arctic.

From the outset, DSDP aroused the interest of the international scientific community. Numerous foreign scientists made contributions to the project as participants aboard the *Challenger*, as members of advisory panels and committees,



New technique. DSDP scientists have finally developed a way to recover drill cores of undisturbed soft sediments. The core section on the left was obtained by conventional means; the one on the right, showing finely detailed layers, was recovered with the new hydraulic piston corer. Both cores are of comparable age and composition.

and by studying samples and data. As a result, in October of 1975 the International Phase of Ocean Drilling (IPOD) was initiated that formalized this spirit of international cooperation. IPOD presently receives $1 million annually for its operational costs from each of five foreign countries (Federal Republic of Germany, France, Japan, Soviet Union, and United Kingdom).

During 1979 the *Challenger* operated in the central part and the eastern rim of the North Pacific and, to a minor extent, in the Caribbean Sea, completing Legs 62 through 68. Leg 62 mainly investigated the development of oceanic plankton communities at the Cretaceous/Tertiary boundary interval, a time of major environmental and evolutionary upheavals that occurred about 65 million years ago. In contrast, Leg 63 was devoted primarily to the study, using fossils contained in the sediments, of the paleo-oceanography of major North Eastern Pacific boundary currents, such as the south-flowing California current.

Leg 64 concentrated on the Gulf of California from a tectonic and sedimentary-stratigraphic standpoint. The gulf is seen by scientists as a model for an early stage in the formational histories of ocean basins and passive continental margins. It may, in addition, hold answers to important questions relative to the tectonism of North America and to the origin of laminated diatomaceous sediments. One of the highlights of Leg 64 and, indeed, one of the important technical achievements of the project as a whole, was the first successful testing of a new hydraulic piston corer. This corer is an important new tool in the study of soft sediments, which are generally disturbed by the normal core drilling aboard *Challenger*. The new corer can recover up to 200-meter-long sedimentary sequences in sections of 4.5 meters each, undisturbed by the drilling. Thus it may now be possible to conduct paleomagnetic and detailed stratigraphic analyses on the soft sediments recovered by the *Challenger*.

The principal objective of Leg 65 was to sample the embryonic ocean crust near the crest of the fast-spreading East Pacific Rise at the mouth of the Gulf of California. Leg 65 also successfully carried out two experiments with down-hole instrumentation, a concept that has been with the project since its inception. Particularly encouraging was the emplacement in Hole 482-C of a down-hole recording seismometer and its later retrieval by the R/V *Kana Keoki*. These experiments clearly point the way to a much wider application of such techniques in future operations.

Leg 66 focused on the nature of the ocean-continent transition across a subduction zone that may have been abbreviated in space and time. To this end, eight sites, spanning from wholly oceanic in nature to wholly continental, were drilled off the western coast of southern Mexico.

During Leg 67 the *Challenger* drilled a transect off Guatemala to test a model for the geological development of the active margin of this region. Leg 68 was planned to deploy again a series of down-hole instrument packages (including stress and permeability measurements, *in situ* televiewers, electrical resistivity experiments, and a magnetometer). The down-hole operations were completed, but the *Challenger* had to dock for repairs in Panama after the first site. Subsequently, *Challenger* entered the Caribbean to begin a short "mini-leg" devoted solely to the piston corer in response to strong urgings from the scientific community. Two sites were successfully occupied, from one of which an apparently undisturbed, 235-meter-long sequence of calcareous Neogene sediments was recovered. This sequence may well become a classic deep-sea stratigraphic reference section.

Ocean Sciences

NSF's ocean science programs support a broad spectrum of research to elucidate oceanic phenomena and processes. These areas include marine biology, chemistry, physics, and geology, as well as studies of marine environmental quality, environmental forecasting, living resources, and seabed assessment. NSF also supports constructing, equipping, and operating the research ships and submersibles needed to carry out this research.

This support has played a major role in fostering a quiet revolution in scientific understanding of the sea. During the past few years important discoveries have fundamentally altered our perceptions of oceanic circulation, seafloor processes, geochemical control of seawater chemistry, size distribution of marine organisms, and the role of ocean temperature in controlling terrestrial weather.

This new knowledge has stimulated improved assessment of the oceans' role in worldwide climate, carbon dioxide distribution, potential fisheries' harvests, and petroleum reservoirs, as well as in such issues as coastal pollution. These trends towards improved understanding of the ocean and enhanced societal application of this knowledge continued in 1979. Some areas of special significance are highlighted on the following pages.

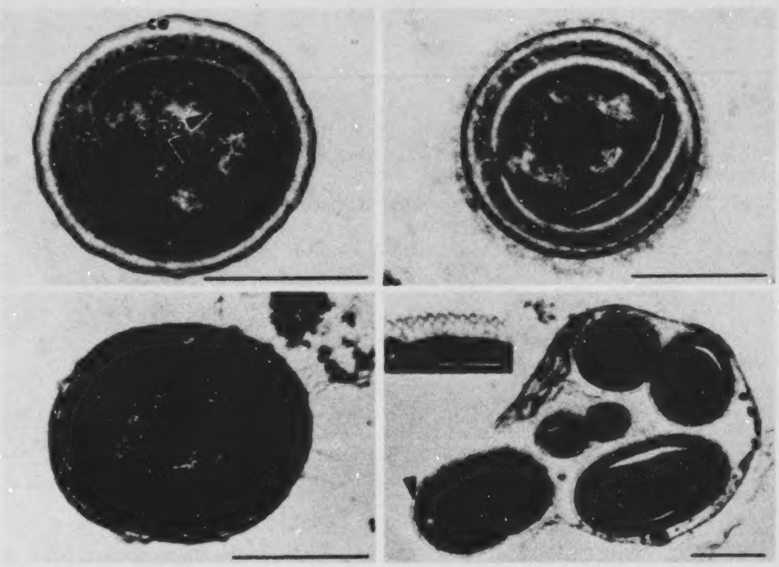
Tropical Oceans: More Productive Than Suspected

Recent work is changing our picture of the productivity and biological structure of the tropical and subtropical open sea. These vast expanses of warm, clear blue water have long been viewed as biological deserts, and this view has been supported by a substantial body of evidence. Average concentrations of nutrients essential for the growth of phytoplankton were very low, and standing stocks of phytoplankton determined by filtering water samples were correspondingly low.

The extreme clarity and blueness of

the water appeared to reflect this paucity of algae. Morever, estimates of phytoplankton productivity obtained by incubating water samples with carbon-14 labeled bicarbonate, concentrating the algae by filtration, and measuring their radioactivity indicated rates of primary production on a volume basis two to three orders of magnitude below those rates found in coastal waters.

But the view now emerging is that these extensive areas of the ocean contain large and relatively active populations of very small organisms. John Sieburth of the University of Rhode Island and Stanley Watson of Woods Hole Oceanographic Institution observed large populations of minute reddish balls which were ultimately identified as photosynthetic cyanobacteria (the so-called blue-green algae). Sieburth reports that these cyanobacteria can comprise up to one-third of the total phytoplankton volume. It is likely that previous studies missed this abundant population because their small size—diameters of less than one micron—permitted them to pass through the filters then in use.



Tropical food chain. Less than 0.001 millimeter in diameter, single-cell bluegreen algae have been largely overlooked in estimates of biological productivity in low-latitude open oceans. These abundant cyanobacteria may explain the discrepancy between mid-ocean fish stocks and the apparently inadequate phytoplankton population to support them.

The primary production of these cyanobacteria is as yet unknown but probably is substantial and sufficient to support associated populations of minibacteria which in numerical abundance approach those of bacteria found in coastal waters. Watson finds the cyanobacteria unusually sensitive to heavy metals and suggests that their contribution to primary production previously may have been missed because care was not taken to eliminate heavy metals adsorbed on the walls of glassware used in primary production experiments.

Rapid photosynthesis and growth by algae and cyanobacteria would require a rapid uptake of nutrients, and recent work by James McCarthy of Harvard University suggests a mechanism by which rapid uptake can occur in nutrient-impoverished mid-ocean waters. He finds that phytoplankton cells, when exposed to high nutrient concentrations, can take up in a few minutes enough nutrients to permit cell division.

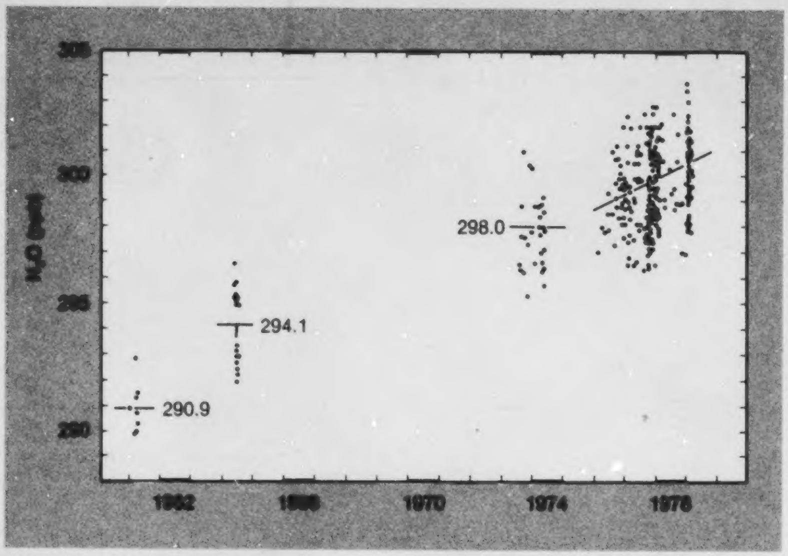
McCarthy points out that, in nature, even though average nutrient concentrations may be uniformly low, nutrients on a size scale approaching that of an individual phytoplankton cell must be extremely variable in space and time and are, for example, likely to be elevated in the vicinity of individual zooplankton. Such patchiness may permit rapid recycling of nutrients and higher levels of plant production than previously thought.

If continued study confirms that presumed oceanic deserts are in fact biologically active, then scientists must reevaluate concepts of marine productivity. Since most of the surface area of the world ocean is comprised of water low in nutrients, greater primary production in low nutrient regions might substantially increase present estimates of total oceanic plant production. Confirmation of greater mid-ocean productivity, for example, would explain the long-standing discrepancy between standing stocks of fish and other consumer organisms and the apparently inadequate phytoplankton production assumed to support these populations.

Ocean's Role in Control of Global Atmospheric Pollution

Nitrous oxide is a compound that both occurs naturally in the environment and is added to the environment by human activities. Introduced to the environment primarily by bacterial denitrification of fertilizers and the combustion of fossil fuels, these additional sources of nitrous oxide have caused a rise in its concentration in the atmosphere. In the mid-1970's, it was suggested that this might pose a serious threat to the ozone layer. Additional concern was expressed regarding a possible "nitrous oxide greenhouse effect" similar to, but less significant than, that associated with atmospheric carbon dioxide.

Fortunately, recent measurements of several chemical reaction rates indicate that the catalytic effect of nitrous oxide on the ozone layer is probably less than thought originally. However, the validity



Nitrous oxide greenhouse? The amount of N_2O in the lower atmosphere has increased at about 0.2 percent per year since 1960. Recent measurements show that the oceans are not a significant source of the N_2O; the rise in concentration may be explained, then, solely by increased combustion of fossil fuel. Efforts to assess the possible atmospheric changes resulting from this rise are continuing.

of the scientific questions raised by the controversy regarding the chemical controls of nitrous oxide in the atmosphere remains undiminished.

Because water covers 70 percent of the Earth's surface and because nitrous oxide can be both released and dissolved in near-surface seawater, the oceans play an important role in determining atmospheric nitrous oxide concentrations. In order to gain understanding of this role, marine chemical research is being conducted at Scripps Institution of Oceanography by Ray Weiss. This research has focused on nitrous oxide gas in the lower atmosphere and in surface seawater of the world's oceans.

One of the primary objectives of this research has been to reduce the uncertainty in the present estimates of the residence time, which ranges from 6 to 200 years, of nitrous oxide in the troposphere (lower atmosphere). The major causes of this uncertainty have been connected with the lack of solid data on the extent to which the oceans are a source of nitrous oxide and on the inverse relationship between residence time and the variability of existing tropospheric concentration measurements.

Measurements carried out during the course of the present research have contributed to the resolution of these problems and to a better understanding of the natural behavior of nitrous oxide. Thousands of underway shipboard measurements in the Atlantic, Indian, and Pacific Oceans showed that the oceans are a comparatively weak source of atmospheric nitrous oxide and thus suggest a long tropospheric residence time.

Measurements of nitrous oxide in the atmosphere were also made aboard ship as part of the underway studies, as well as in the laboratory on air samples from a number of monitoring stations. The air samples also included several collected in the early 1960's. Both the shipboard and laboratory results show remarkable uniformity over large geographic areas, again consistent with a long residence time.

Over time, however, the recent and historical air samples both show a significant increase of about 0.2 percent per year, which is consistent with published figures for nitrous oxide production by combustion of coal and fuel oil if the tropospheric residence time is long. This rate of increase is less than that predicted if denitrification of fertilizers is a major source of nitrous oxide. Thus, the data are gradually pointing toward an understanding of the spatial and temporal distribution of tropospheric nitrous oxide.

Further measurements to substantiate the rate of increase and to better determine the magnitude of anthropogenic sources, especially combustion, will remove the major uncertainties in these relationships. It is important to note that because nitrous oxide is an efficient "greenhouse" gas, its observed rate of increase is roughly equivalent to one-fifth of the greenhouse warming due to the present rate of increase of atmospheric CO_2.

An unexpected finding of this research, which has enhanced its significance, is that nitrous oxide is an exceptionally sensitive tracer of ocean upwelling and mixing dynamics. Coupled with the recently expanded capability to measure dissolved methane and carbon dioxide simultaneously—along with Weiss' success in measuring directly the solubility of nitrous oxide in seawater—these gases show promise as extremely valuable oceanographic tracers.

Fish Skeletal Debris: A New Stratigraphic Tool

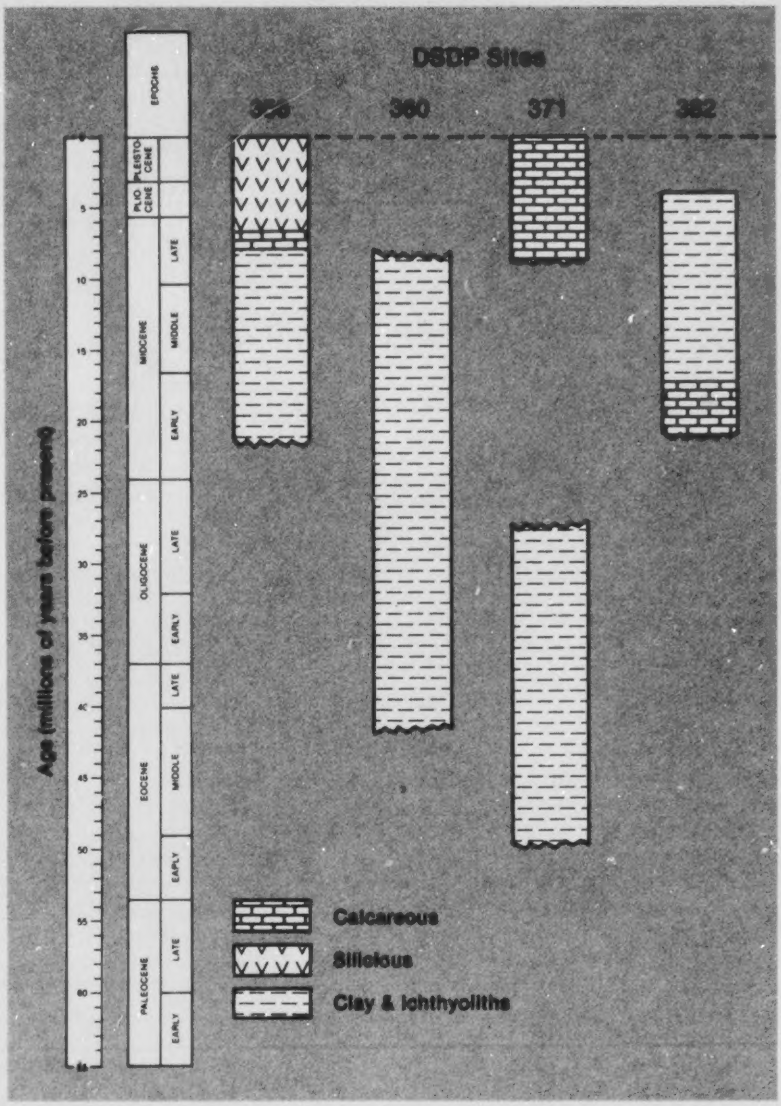
For the past several decades sedimentologists and micropaleontologists investigating sediment cores from the floor of the open ocean have recognized that microfossil remains have enormous value, both for interpreting the sediment's age and for tracing the development of the circulation patterns of the overlying waters.

Sediment deposition is highly variable from place to place, and it is these variations in sediment components and their rates of accumulation that are direct clues to understanding how the oceanic circulation has evolved. For example, vast areas of the open ocean floor have been deeply scoured or stripped bare of sediment, indicating the presence of strong near-bottom current systems that were not previously recognized. Major seaways have continually opened and closed as a consequence of crustal plate motions and as continental ice sheets have undergone numerous episodes of advance and retreat. Tectonic and climatic events such as these have profound effects on the biological, chemical, and physical characteristics of the oceans, and these effects are best documented through a careful unraveling of the depositional record on the seafloor.

Among the most powerful tools for interpreting the history of the oceanic circulation are fragments of microfossils, which range in size from several microns up to several millimeters. These fragments, generally composed of calcium carbonate or opaline silica, represent the "hard parts" of phytoplankton and zooplankton that lived in the overlying waters. Four major groups of microfossils (foraminifera, radiolaria, nannofossils, and diatoms) have received the greatest amount of attention up until now. However, because of the oceanic circulation patterns and seafloor topography, the four common microfossil groups are not preserved in sediments from all regions.

The vast anticyclonic gyres characteristic of middle latitudes are a good example. Within these gyres, plankton productivity is low, sediment deposition rates are very low, and bottom waters have sufficient time to corrode and dissolve most of the calcareous and siliceous microfossils. The residual sediment in these areas, generally referred to as "red clay," was for many years considered to be devoid of any material that might be useful for stratigraphic and paleo-oceanographic studies. Thus, the vast areas of the ocean floor beneath the subtropical gyres remained a major question mark in the understanding of how deep-ocean sediments accumulate and how these sediments reflect the history of the overlying waters.

A team of investigators at the University of California's Scripps Institution of Oceanography (Patricia S. Doyle, William R. Riedel, Carol E. Natland, and Phyllis B. Helms) has recently devoted particular attention to these "red clay" regions. They discovered that the microscopic teeth and scales of fishes (composed of calcium phosphate) persist in open-ocean sediments long after the better-known calcareous and siliceous microfossils have been dissolved.



Fine detail. The tedious classification of microscopic bits and pieces of fish skeletons in barren red clay sediments has permitted age-dating of previously undecipherable deep-ocean-floor deposits. The four drilling sites represented—with long sections of seemingly featureless clay deposits—are example of places where analysis of skeletons can now reveal ages. Results will help understand how fast the sediments have accumulated, their relation to circulation of the overlying waters, and historic changes in ocean envirionments.

The fish fragments, also referred to as "ichthyoliths," had been noted from time to time since the original *Challenger* expedition over a hundred years ago, but no attempt was made to use them for age determinations until sediment cores obtained by the Deep Sea Drilling Project became available for study nearly 10 years ago. During this past decade, the research team at Scripps has discovered that the ichthyoliths do indeed have great stratigraphic value. As a result there is increasing promise for extending paleooceanographic interpretations to the vast, relatively barren red clay regions of the deep ocean.

Fish skeletal debris presents a special problem that is not characteristic of other microfossil groups: It is very difficult to relate the observed ichthyoliths (which are largely teeth, bone fragments, and scales) to the particular kind of fish from which they came. Consequently, the Scripps research team has chosen to use descriptive terms for classifying the fragments, rather than employing the more commonly used system of generic and specific names. For example, three types of fragments that occur only in the latest Cretaceous (approximately 65 to 80 million years ago) have been given descriptive names such as "kite-shaped longitudinal line," "striated blunt triangle," and "centrally striated triangle." Similarly distinctive descriptive labels have been assigned to approximately 85 other forms of fish debris from sediments which range in age from the present back to nearly 80 million years.

The research team focused their initial efforts on DSDP cores and well studied sections on land in which the ichthyoliths co-occur with one or more of the major microfossil groups. In this way, the stratigraphic limits of the individual types of ichthyoliths could be established independently. By studying a number of such sections from widespread regions, the researchers verified that the age ranges of the ichthyoliths are nearly the same worldwide.

Having established the wide geographic extent of these "datum levels," the research team then began to apply their technique to the vast red clay regions, where ichthyoliths remain the only biogenic materials for sediment study. For example, the team has recently completed the analysis of a 24-meter giant piston core from the red clay region beneath the North Pacific gyre. They have been able to use their ichthyolith stratigraphy to establish that there has probably been continuous sedimentation at this site from the late Cretaceous to the late Cenozoic (i.e., the past 80 million years), at a rate of 0.2 to 0.3 meter per million years. This particular core, because of its probable stratigraphic continuity, is now serving as a reference section with which shorter core intervals from other regions can be compared.

The team is now re-examining the extensive amounts of DSDP core material that previously received little attention because it was considered to be "barren." Through these continuing studies, the rapidly evolving techniques of microfossil biostratigraphy and paleoecology can be extended into the vast subtropical regions that were formerly considered to be relatively inaccessible.

International Decade of Ocean Exploration (IDOE)

Study of the interactions between the ocean and the atmosphere has been a long-term objective of oceanographers and meteorologists involved in NORPAX (the North Pacific Experiment). This environmental forecasting research into air-sea interactions has been done in many ways—large-scale studies of ocean properties, small-scale studies of ocean processes, numerical modeling of selected processes, and statistical analysis of observed data, to name a few.

An interesting example of this research is recent investigations where the surface of the Pacific was divided into oceanic and atmospheric variables, including sea-surface temperature, surface atmospheric pressures, and wind speeds over large ocean areas. A type of statistical technique known as principal component analysis was then performed to see if there were a possibility of predicting events. That is, if one or a combination of variables is known, can a forecast be made of the variables for sometime in the future? In fact, the wind field over part of the equatorial Pacific can be used to make short-term (1- to 3-month) predictions of oceanic and atmospheric variables. This short-term predictability is mostly due to persistence, or the tendency for things to carry on by "inertia."

But what about longer forecasts? Abnormal weather conditions over a few months—what might be called modest "climatic changes"—are of special interest. One well-known short-term climatic change is an occasional warming of surface waters in the eastern Pacific that lasts for a few months. This climatic change is most dramatically expressed off Peru where it causes a catastrophic collapse of the fisheries. The event, known as El Niño, is not only felt throughout the Pacific, but is reflected in changes in the weather over the United States. It would be of significant benefit to forecast an El Niño.

In fact, the NORPAX statistical calculations show that an El Niño can be forecast. Knowledge of the equatorial Pacific wind field can now be used to make a long-term prediction (8 to 15 months beforehand) of the anomalous warming off Peru that is associated with an El Niño. Although some time is needed to analyze the wind data, it is routinely available and the El Niño can be calculated 10 to 12 months in advance. Thus, scientists have learned how to forecast significant changes in the world weather with long lead times based on changes in the Pacific.

In the area of seabed assessment, scientists from five U.S. institutions collaborated with French and Mexican scientists to study processes of ocean crust formation along mid-ocean ridge spreading centers. Project RISE (*Rivera Submersible Experiment*) investigated the northernmost segment of the East Pacific Rise near the mouth of the Gulf of California. This site has a fast rate of spreading (6 centimeters per year) and is logistically accessible for deep-diving submersibles. Previously, slow-spreading ridges have been studied: 4.0 centimeters per year at the Galapagos spreading center and 2.5 centimeters per year at the 1974 French-American Mid-Ocean Undersea Study (FAMOUS) area of the Mid-Atlantic Ridge.

The RISE diving program was conducted in two phases. In 1978 the French submersible *Cyana* discovered massive metal sulfides along the axis of the East Pacific Rise at depths of 2,500 meters. Such features are significant; scientists have long postulated that massive sulfides found in exposures or rocks on land had formed in the deep ocean, but the process had never before been observed.

The *Cyana* expedition installed a navigation system on the bottom to guide the U.S. submersible *Alvin* back to the same site for the second phase in 1979. The *Alvin* operation was designed to measure physical properties of near-surface seafloor rocks (to depths of 200 meters below the ocean bottom). Since *Alvin* is a very stable platform, the measurements were ten times more precise than those recorded from ships. Some innovative techniques were used, including an *Alvin*-mounted hammer striking the sea floor to send out signals that were recorded by seismometers deployed on the sea floor.

An *Alvin*-mounted gravimeter was able to resolve gravity anomalies on the order of 5 to 10 milligals. These data suggest that a magma chamber lay under the spreading center. Processes of ocean crust emplacement were also investigated by studying the magnetic field recorded in seafloor rocks. Periodic reversals of the Earth's magnetic field are recorded by zones of polarity reversal in the rocks on the sea-floor. The nature of the process is believed to be closely associated with the process of crustal emplacement. The most recent reversal occurred 700,000 years ago and is found in rocks 20 kilometers west of the East Pacific Rise. The *Alvin*-mounted magnetometer/gradiometer better delineated the transition zone, made several *in situ* measurements, and collected samples for chemical and mineral analyses. Analyses of these data will provide insights into the process of crustal emplacement magnetic reversal.

A ship-mounted camera system that takes photos covering half an acre of sea floor recorded an area of chimney-like features (some rising 10 meters above the sea floor) jetting out mineral-rich, hot water (350° C) at 10 meters per second. Samples of these mineral-rich waters and recently deposited sulfide minerals from the axis were collected by *Alvin*.

The presence of active hydrothermal vents on the sea floor has major implications for: (1) studies of processes controlling chemistry of seawater, (2) heat flow in the oceanic crust, and (3) processes by which minerals are mobilized to form economic ore deposits. Some of the world's major ore deposits consist of assemblages of pillow lavas, metalliferrous sediments, and massive metal sulfide deposits. These deposits, believed to be formed by hydrothermal processes at constructive plate boundaries, had never before been found in place on the ocean floor. The deposits in the RISE area indicate that processes inferred from studies of presumed ocean crust now exposed on land are still active on the East Pacific Rise.

Oceanographic Facilities and Support

Oceanography is highly field-oriented and, as such, is heavily dependent on facilities that enable the scientist to collect data at sea. Ships and other platforms, and their costly equipment, consume a substantial portion of support for the science. Consequently, the status of the fleet of ships operated by academic institutions is a matter of community-wide concern. Although this fleet is funded from a variety of Federal and non-Federal sources, the Foundation's role is decisive, funding two-thirds of operating costs, most of the equipment and upgrading, and virtually all of the new construction for replacements.

Fiscal year 1979 marks the beginning of a period of change with respect to the academic fleet, which has numbered 28 to 29 ships since 1974. Shifting patterns of funding and changing technology have resulted in persistent underutilization of the larger ships in the fleet. Fortunately, a long-planned construction program for coastal ships is well underway and offers a positive means to modify fleet composition and costs.

The first new coastal ship was awarded to the University of Miami and will replace the 63-meter (208-foot) R/V *Gilliss*. It will be constructed in accordance with one of two Foundation-owned designs developed under the aegis of the University-National Oceanographic Laboratory Systems (UNOLS) over the past 3 years. These designs are expected to add a capability not previously available to the oceanographic community—ships with good sea-keeping characteristics for year-round operations, with adequate working space and capacity for handling modern instruments, yet cost-effective for frequent short cruises necessary for seasonal geographic coverage of coastal processes.

The need for fleet adjustments took on an even greater urgency in 1979 owing to the sudden escalation in fuel prices. The rapidly rising cost of oceanographic equipment, driven by new technology as well as inflation, also argues for reduction in size of the fleet to enable a major upgrading in the quality of gear.

Recognizing this need, UNOLS sponsored a workshop in February 1979 to define the basic minimum ship and instrumentation capability, operation, and maintenance that a scientist should expect to find aboard the several classes of ships in the fleet. The workshop discussed and defined areas where equipment standardization among the ships is desirable and further discussed certain standard maintenance and use practices. Areas where additional study are needed were also identified and methods of further study established. Ongoing efforts initiated by this workshop will contribute significantly towards maintaining and improving the overall capabilities of the academic fleet.

In addition to surface ships, NSF also supports a deep submergence system consisting of the research vessel *Lulu* and the deep submersible vehicle *Alvin*. *Alvin*, based at the Woods Hole Oceanographic Institution (WHOI), is owned by the U.S. Navy and operated by the WHOI marine operations staff. The *Alvin/Lulu* system has been designated a UNOLS National Facility and is available for qualified research projects selected on the basis of scientific merit and compatibility of the proposed research.

Major funding for *Alvin* operations is provided by NSF, the National Oceanic and Atmospheric Administration (NOAA), and the Office of Naval Research (ONR). The maximum operating depth is 4,000 meters; during normal operations one or two scientific observers are submerged for 6 to 8 hours. The life support system will sustain three persons for 72 hours.

This year's most dramatic activities aboard *Alvin* occurred during the exploration of a region of hot water vents in the deep-sea floor near Ecuador. Scientists recovered a 2.6-meter specimen of a sea worm. The worm, which is pink with a brilliant red tip, lives in a 2.5-centimeter-diameter tube and is the largest creature yet recovered from the area.

Because of concerns regarding the useful life expectancy of the *Alvin/Lulu* system and its ability to support submersible science requirements in the future, a UNOLS study is being initiated this year that will undertake the assessment of the current and projected requirements for submersible science facilities, to review the alternatives to meet those requirements, and to recommend specific systems for short-term and long-term needs. This study is jointly supported by NSF, ONR, and NOAA.

United States Antarctic Research

Approximately 85 U.S. research projects were performed in Antarctica during the 1978-79 antarctic summer in biology and medicine, oceanography, earth sciences, glaciology, meteorology, and upper atmosphere physics. McMurdo, South Pole, Siple, and Palmer stations were operated year-round. The Foundation published a draft environmental impact statement on the U.S. Antarctic Research Program and published regulations pursuant to Public Law 95-541, the Antarctic Conservation Act of 1978.

A major study of the Ross Ice Shelf was concluded during the 1978-79 summer season. The shelf is a floating mass of snow and ice the size of Texas that overlies much of the Ross Sea between the Transantarctic Mountains and the West Antarctic Ice Sheet. The ice shelf is important because it dams much of the West Antarctic Ice Sheet, which, if all of it flowed to the sea and melted, would raise sea level some 6 meters, causing major flooding of low-lying coastal areas and significant changes in global climate.

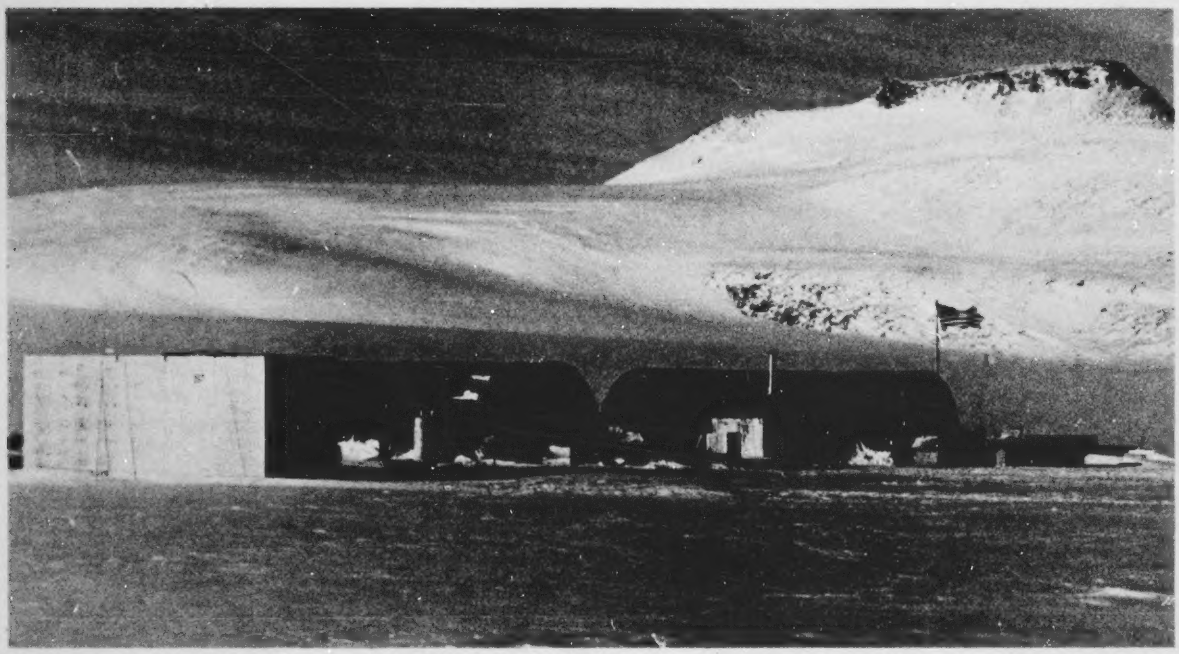
The Ross Ice Shelf Project involved geophysical, glaciological, and biological studies and featured the boring of holes through the 420-meter-thick shelf both for access to the sea and sediments below and for coring and studies of the ice itself. Examination of the core proved that sea water freezes to the bottom of the shelf at that location; earlier coring at a more northerly spot revealed bottom melting. The thickening in the southern part is causing more of the ice shelf to ground, and in turn is causing thickening of the West Antarctic Ice Sheet as well. These studies therefore do not support the theory advanced by some glaciologists that the West Antarctic Ice Sheet is rapidly disintegrating.

Byrd Glacier, on the western boundary of the Ross Ice Shelf, is one of the biggest and fastest-moving outlet glaciers in Antarctica, moving through a pass in the Transantarctic Mountains at a rate of more than 800 meters a year. It is 150 kilometers long and 25 to 50 kilometers wide. Byrd Glacier drains 6 percent of the East Antarctic Ice Sheet, and it has a critical influence on the Ross Ice Shelf. A major camp was established during the 1978-79 antarctic summer to support geological, glaciological, and other studies there and at the neighboring Darwin Glacier. Teams from the University of Maine completed detailed photogrammetry and ground control to investigate the ice stream and its interaction with the Ross Ice Shelf. Glacial-geology studies were performed to determine the fluctuations of glaciers in the area over the past several thousand years. Measurements to date indicate that Byrd Glacier has thinned 1,200 meters since the last ice age and that further thinning has been substantial and recent.

The antarctic krill (*Euphausia superba*) is an important species in the food web of the southern ocean. A large number of the species of fish, penguins, flying birds, seals, and whales living in the waters surrounding Antarctica depend on krill for their food. Because of its extraordinary abundance, antarctic krill has particular significance as a potential major new source of protein for humans. The chemical composition and nutrient value of krill products and fish protein concentrate are equivalent.

Despite sometimes intensive studies performed as early as the 1920's, there are significant discrepancies and deficiencies in the present knowledge of krill abundance. For example, published estimates of the standing stock of krill vary from 125 million to 15 billion metric tons. Estimates of the annual sustainable yield of krill also vary widely, including an upper figure that is more than twice the 70 to 80 million metric tons that is the current yield of the world's fisheries. Much of the uncertainty in these figures arises from the lack of information concerning the basic biology of the species.

NSF has expanded its marine biology research facilities at Palmer Station, located on an island near the Antarctic Peninsula, in order to support studies of krill biology. A team from DePaul University, headed by Mary Alice McWhinnie, has since 1977 been performing research on krill at this laboratory and at a lab-



Field camp. During the antarctic summer more than 50 geologists and glaciologists, supported by helicopters from this site at Darwin Glacier, studied the movements of glaciers feeding the climatically important Ross Ice Shelf. (Photo by Frank Bair Jr./U.S. Navy)

oratory in Chicago. Many of the Palmer station studies were made using flow-through seawater aquaria. Krill were maintained in the aquaria for over a year with good survival rates. Previously, researchers had thought that this species could not be maintained in a laboratory for long-term study. The DePaul team's findings in some cases differ from previously published conclusions. For example, they find that:

- Krill are omnivores. In an aquarium environment, even when given plenty of phytoplankton, krill will even eat other krill. Previously they were thought to feed exclusively on phytoplankton.
- Krill females spawn, molt, feed, and *spawn again*. They may even spawn a third time. Previously, they were thought to die after one spawning.
- Krill spawning occurs in the upper 100 meters of the water column, and both spawning and development can occur at sea level. Previously, it was thought that spawning and development required hydrostatic pressure.

Despite these advances, some fundamental features of the biology of antarctic krill are poorly known. These include life span, growth rates, the precise nature of swarming behavior, and accurate numbers of krill in the sea.

In 1979 the Foundation and the Argentine Navy successfully completed 5 years of shared use of the ice-strengthened research ship USNS *Eltanin*. Earlier, between 1962 and 1972 the ship had made 52 cruises in antarctic waters, supporting research in physical oceanography, marine geology and geophysics, and marine biology. Then, in 1974, the ship, renamed ARA *Islas Orcadas*, returned to service as a research platform under Argentine supervision. As *Islas Orcadas* the ship made 14 cruises in the little-explored far South Atlantic Ocean, completing the circumantarctic survey originally planned for the ship. The vessel covered 111,000 nautical miles (206,000 kilometers) in 708 days at sea. On August 1, 1979, the ship was returned to its owner, the United States Navy.

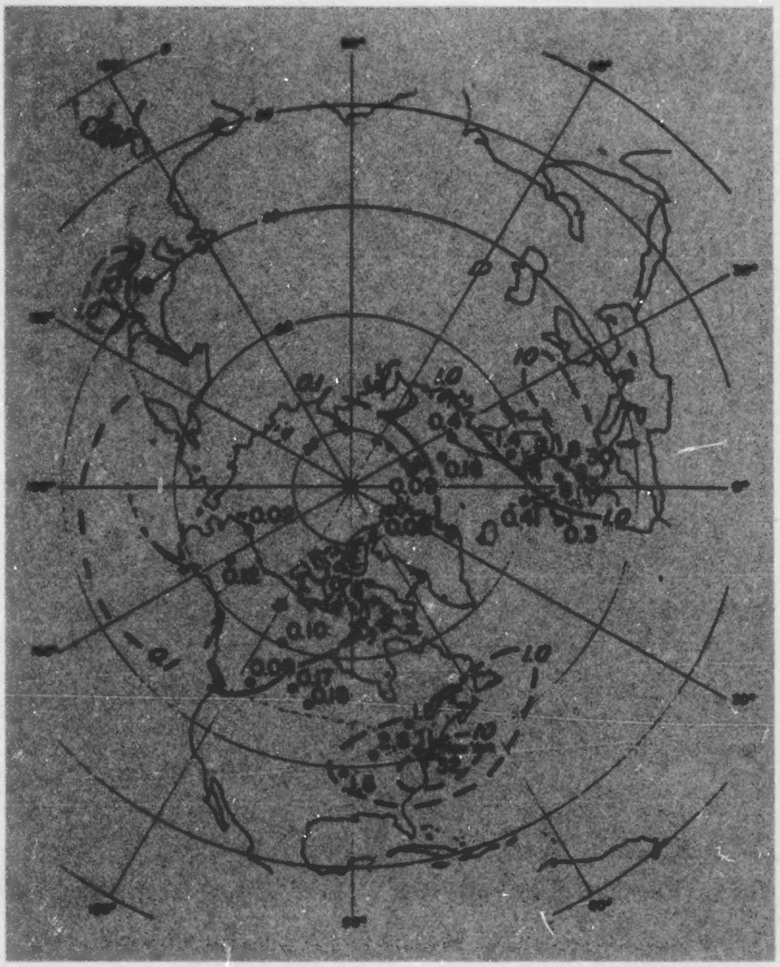
Arctic Research

Since the 1950's, pilots and weather reconnaissance crews flying over the Arctic Ocean have reported a heavy haze, especially in the spring, that can reduce visibility aloft to less than 10 kilometers. Because the Arctic is so far from the world's sources of air pollution, it might be supposed that the haze has a natural cause. However, evidence has begun to accumulate that part of the arctic haze may originate in industrialized regions of the Northern Hemisphere.

Beginning in the late 1960's, air chemists measured unexpectedly high concentrations of carbon monoxide on the ice sheet in northern Greenland and found aerosol layers over Greenland with very high numbers of particles. Regular incursions of pollution-derived aerosols and gases into southern Scandinavia and northern Norway also were observed.

Later, Kenneth A. Rahn of the University of Rhode Island and Glenn E. Shaw of the University of Alaska measured the aerosols at Barrow, Alaska, and found that Barrow's air in winter contains easily detectable amounts of aerosol pollutants. Because of its chemical makeup, the aerosol must come from the mid-latitudes, probably the United States and central Europe.

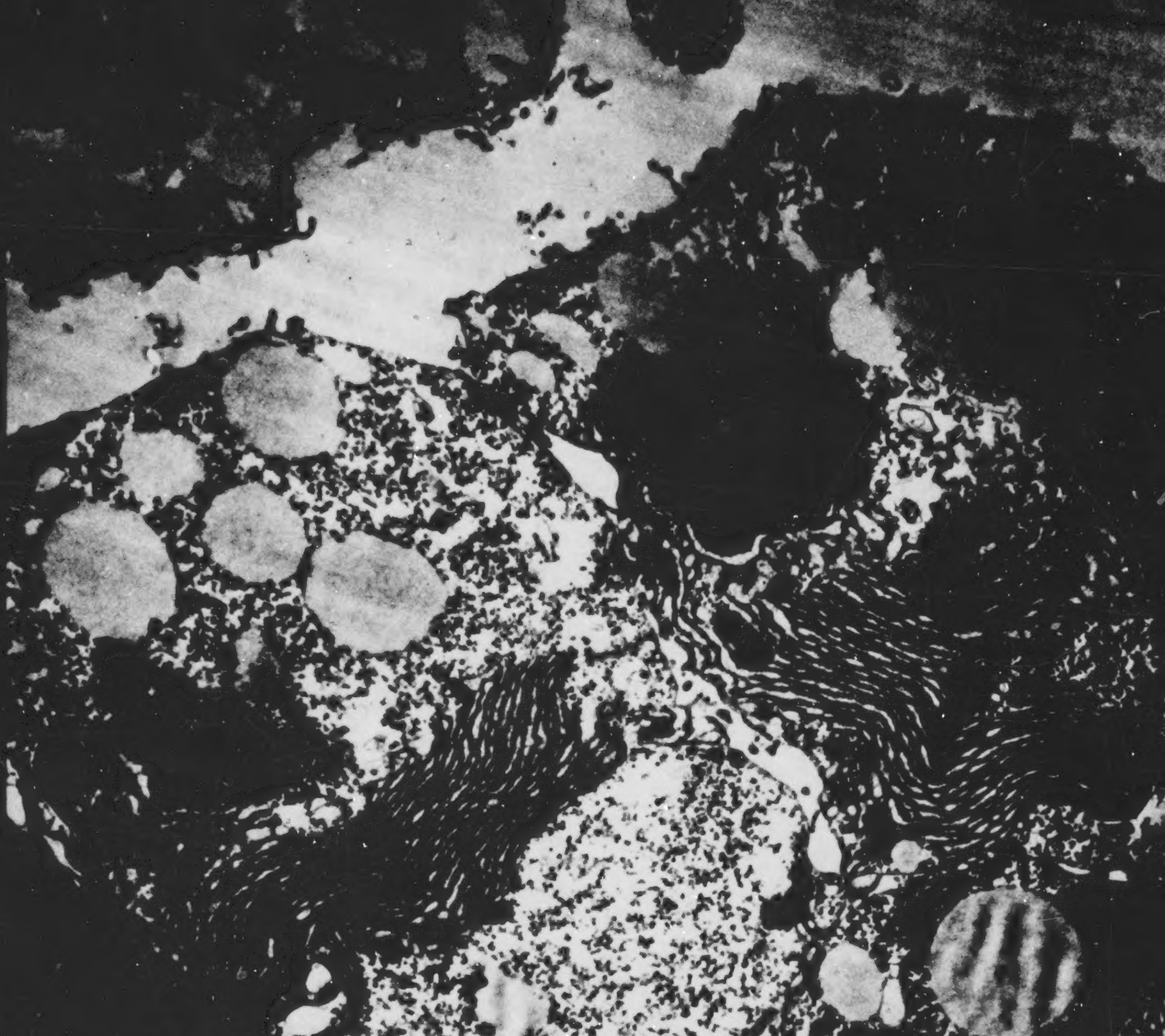
Rahn and air chemists from other countries now have established an air sampling network of 13 stations—10 in the Arctic and 3 in pollution-source regions. Work to date has established that the arctic haze often extends over thousands of square miles, that there is a strong seasonal variation in aerosol pollutant levels, and that the haze contains much sulfate, generally as dilute sulfuric acid. "Excess" vanadium resulting from the burning of fuel oil, they found, seems to be a reliable indicator of long-range transport of aerosols. The measurements are continuing. An understanding of arctic haze is important because of its possible effect on climate and the tundra ecosystem.



Global pollution. Summer measurements of atmospheric vanadium (shown here in nanograms per cubic meter), a product of fuel oil combustion, seem to be a reliable tracer of other pollutants as well. The lowest reading was near Barrow, Alaska, and the highest near New York City.

In May, a ski-equipped C-130 airplane, usually operated in support of the U.S. Antarctic Research Program completed a several-year effort to measure the thickness of the Greenland ice sheet. With special antennas suspended from its wings, the plane crisscrossed the enormous island while recording the echoes of transmitted radar pulses. The echoes show both the elevation of the ice surface and the topography of the underlying bedrock—essential information for glaciologists and others studying past climates of the region. A map showing the information is being prepared.

Other arctic research was performed in 1979 on terrestrial and offshore permafrost, on the Bering Sea ecosystem, and on atmospheric processes and constituents.



60

Biological, Behavioral, and Social Sciences

3

In the fields encompassed within the Biological, Behavioral, and Social Sciences, NSF's role in support of basic research at universities is of high importance. In several cases it has a unique role among Federal agencies. The responsibility often extends beyond what might be attributed on the basis of the budgets of these programs in that it represents the sole source of Federal support.

In addition, the importance of nurturing research in a fledgling scientific subdiscipline through its initial descriptive phase to a productive analytic phase is often not perceived until it can be evaluated in hindsight. It is not surprising, then, that precise measures of cost-benefit analyses and other techniques typical for formal planning have not been established for this kind of support activity. Nevertheless, there is evidence from experience that NSF's investment in a number of basic research areas has been catalytic and meaningful beyond the dollar expenditure in any given fiscal year.

To provide perspective on the matter, the following are cited: Ecology, which was first achieving recognition as an independent discipline coincident with the establishment of NSF some 30 years ago, now boasts of progress in understanding the workings of whole ecosystems. An excellent example is seen in this chapter's description of findings at the ecosystem-level of tropical forests. In connection with that research, nutrient-cycling projects are of special interest as we attempt to gain greater insight, for example, on the movement and exchange of carbon dioxide between soil, vegetation, water and the atmosphere and with acid rain.

Physical anthropology, another case of nurturing, was first supported as a small, adventuresome effort in NSF's early days. Today, NSF represents the major source of Federal support for the broad field (i.e., physical and cultural anthropology and archaeology) and is virtually the only agency that maintains an extramural basic research program for investigator-initiated research. Largely through the cumulative efforts of NSF-supported scientists, we now have evidence of human existence millions of years earlier than most would have imagined possible. Further systematic study of human origins through the combined efforts of geologists, archaeologists, anthropologists, and ecologists lends promise that we may take a major step in understanding primate evolution within the next 5 to 10 years.

In a somewhat different vein, NSF supported the development and publication of the American Sign Language (ASL) dictionary. This effort was greatly ridiculed more than a decade ago. Today, sign language is generally acknowledged to be a valid alternative mode of communication for those unable to sound and/or hear the spoken word. Further, the systematic understanding of this distinctive human behavior has had practical benefits for those with learning problems or in need of rehabilitation from accident. And while the extent to which the nonhuman primate can learn, understand, and transmit ASL remains controversial, most scholars with serious acquaintance with the issue support the importance of maintaining a reasonable research effort on the topic.

Research in economics—with emphasis on its mathematical associations—was another early recipient of NSF support.

Table 4
Biological, Behavioral, and Social Sciences
Fiscal Years 1977, 1978, and 1979

(Dollars in Millions)

	Fiscal Year 1977		Fiscal Year 1978		Fiscal Year 1979	
	Number of Awards	Amount	Number of Awards	Amount	Number of Awards	Amount
Physiology, Cellular, and Molecular Biology	1,169	$ 51.34	1,275	$ 57.64	1,344	$ 62.57
Behavioral and Neural Sciences	619	23.81	737	28.47	783	33.07
Environmental Biology	587	30.17	607	31.49	685	33.95
Social and Economic Science	375	21.29	419	24.25	460	25.39
Total	**2,750**	**$126.61**	**3,038**	**$141.85**	**3,272**	**$154.98**

SOURCE: Fiscal Years 1979, 1980, and 1981 Budgets to Congress—Justification of Estimates of Appropriations (Quantitative Program Data Tables).

Since that time economics has grown more sophisticated and is better able to cast light on the fundamental nature of the workings of the U.S. and world economies. Just as environmental research elucidates the nature of acid rain or the importance of a given ecosystem but does not attempt to engage the political policy aspects necessary for correction, NSF's program in economics concentrates on providing basic data on employment, productivity, inflation, and other central topics, but does not address the political and policy aspects of these.

The foregoing illustrates a small portion of the range of NSF's effort in the biological, behavioral, and social sciences. Most of the activity and funds are concentrated in the biological sciences. However, the behavioral and social sciences have been highlighted in these introductory remarks in part because they have, in recent years, attracted heightened public inquiry questioning the expenditure of tax dollars in their support. We trust that the foregoing reminders and the following reports of progress demonstrate the continuing importance and value of NSF's mission to advance knowledge in such basic research.

Physiology, Cellular, and Molecular Biology

Biological research at the cellular and molecular levels of organization focuses on two principal questions: How does the system work, and what controls or regulates it? Each of these questions subsumes another set and often leads to the realization that still more unsolved problems lie ahead. Yet enormous advances have been made in very recent years, thanks to the development of increasingly precise and sophisticated experimental techniques as well as to a greater appreciation for earlier discoveries. Moreover, major applications—such as the control of insect populations, plant breeding programs, and control of treatment of genetic or physiologically based diseases—have been emerging from fundamental biological research.

How genes are activated, or turned on and off, is an example of the complexity of the questions asked experimentally. Activation may be localized within the cell or initiated by an external agent or stimulus. This leads to the major question of how the signal for gene activation is transmitted from outside the cell, through its complex internal structures, to the site of the gene or genes. Thus, knowledge of the phenomena involved in inter- and intracellular communication is critical to an understanding of the regulation of cellular activities. Hormonal action, cell surface proteins, membranes, and metabolic pathways exemplify areas of research central to our ability to answer basic questions about gene activation.

At the subcellular level, new and provocative observations are being made on the role of calcium. In muscle cells, for example, the amount of an important enzyme, calcium-transport ATPase, may be regulated by the concentration of intracellular free calcium. Changes in the intracellular membranes of skeletal muscle cells during chick embryonic development appear to be closely related to the production and regulation of this enzyme. Calcium has also been cited as a major factor in the early stages of zygote division following fertilization. Moreover, calcium is instrumental in relaying hormonal messages within cells.

With the availability of recombinant DNA techniques, the mechanisms of gene action in plants, as well as in animals, can be probed. Use of this technique has revealed more information on the regulation of the photosynthetic capacity of plants and on the role of the chloroplast DNA during plant development. The controlling element system in corn, described in "The Dynamic Genome" in this section, is a classic example of genetic and molecular studies in plants for both basic and applied research.

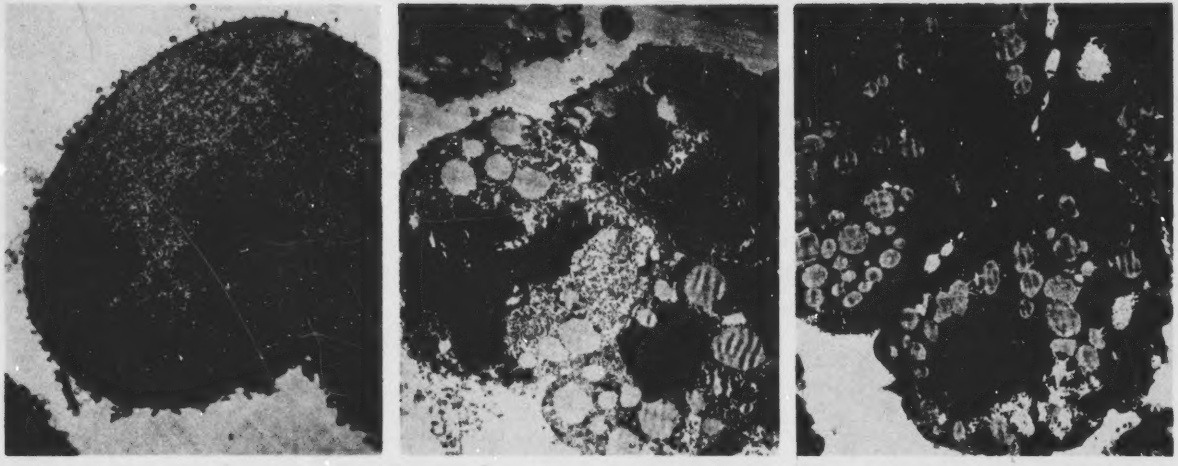
Recent advances in plant cell culture and the availability of recombinant DNA techniques provide opportunities for the introduction of new characteristics or the control of undesirable ones. Entire plants can be regenerated from isolated cells in an orderly progression of events that does not require changes in the genetic material. For example, the production of a strain of potatoes resistant to virus X is possible by selecting single cells of an adult plant that show resistance and inducing such cells to regenerate whole plants. More recent efforts include the induced fusion of protoplasts from different varieties of potato to attempt the production of a super potato.

The knowledge generated by these research endeavors yields information that can often be transferred from one biological level to another, with each profiting from the other. Such efforts nourish further interrelated discoveries of new knowledge.

Mechanisms of Gene Regulation

The regulation of gene activity in eukaryotic organisms (whose cells have true nuclei, as opposed to the simpler procaryote bacteria and blue-green algae, which have a primitive nuclear structure) is central to such important physiological processes as protein synthesis and cellular differentiation. Through interactions with the organism's genetic material in cells, many hormones, especially steroids, affect how much of particular proteins are made.

Within a cell the hormone binds to a specific receptor, modifying the hormone-receptor complex, and then this complex binds to an acceptor site in the nucleochromatin. Specific genes in the region of this binding become active and transcribe their genetic information to a messenger RNA, which migrates to the cytoplasm (cellular material outside the nucleus). There the message on the RNA is translated to produce specific proteins.



Effects of hormones. When the liver cells (left) from a normal male *Xenopus* toad are treated with the female hormone estradiol, they begin to form internal structures (middle) capable of producing egg-yolk proteins. These induced structures mimic those normally present in the female liver cells (right) and show how hormones, binding to cells, can regulate their genetic activity. (Photos by Lawrence Wangh/Brandeis University)

Lawrence J. Wangh at Brandeis University is studying the effects of steroid hormones on protein synthesis using liver cells of the clawed toad *Xenopus*. In female *Xenopus* the major proteins of egg yolk are derived from a protein, vitellogenin, which is synthesized in the liver of mature females, secreted into the bloodstream, and incorporated by growing eggs. The hormone estradiol regulates the vitellogenin synthesis in females, and injection of the hormone also induces vitellogenin synthesis in male liver, which normally does not produce this protein.

Cells purified from *Xenopus* liver can be maintained in a laboratory culture and induced to synthesize vitellogenin in response to estradiol. The addition of another hormone, glucocorticoid, increases synthesis and secretion of serum albumin.

This reflects what actually occurs within the liver of *Xenopus*; some genes are regulated by estrogens and others by glucocorticoids. During the course of development, a particular gene will become active only when the required type of steroid is present.

Eukaryotic genes may be activated by factors other than hormones. Injury to mammalian skeletal muscle induces regenerative processes, which are being followed by George H. Jones at the University of Michigan. Using the drug Marcaine, which completely destroys muscle fibers so that subsequent regeneration is due solely to the formation of new fibers, he is comparing the abilities of undamaged and regenerating muscle to synthesize the contractile proteins myosin and actin. Possible control of gene expression at the levels of transcription and translation can then be assessed in regenerating muscle.

Environmental factors may also trigger gene activation. Winter flounder, inhabiting the coastal waters of the eastern United States, produce a group of serum antifreeze peptides in the winter to keep from freezing in the subzero waters near shore. The appearance of these antifreeze peptides is preceded by the production in the liver of messenger RNA's coding for the antifreeze peptides. These studies, performed by Yuan Lin DeVries at the University of Illinois at Urbana-Champaign, suggest the control of antifreeze production, which is induced by short days and low temperatures, occurs both at the transcriptional and post-transcriptional levels.

The adoption of the techniques of molecular biology by physiologists is thus leading to a fruitful investigation of one of the major unsolved problems in the life sciences, namely, the mechanism by which the transcription of specific genes is regulated in higher organisms. In contrast to prokaryotes, where it is well established how regulatory proteins inhibit or activate the transcription of particular genes by binding to specific sites on the DNA, analogous regulatory mechanisms in eukaryotes are only beginning to be understood.

Plant Molecular Biology

Understanding how plant hormones act is of vital importance to crop productivity, because they have major effects on plant growth, propagation, flowering, fruiting, and defense from adverse environmental conditions. Robert S. Bandurski at Michigan State University and Shang Fa Yang at the University of California, Davis, are continuing their studies on the plant hormone known as IAA, and on the newly discovered hormonal action of ethylene.

Bandurski and his colleagues have been investigating the chemistry of IAA and its various forms for many years. In all the plants they have analyzed, most of the IAA is bound either to a sugar or to an amino acid. Recently, Bandurski showed that the binding of the hormone to a sugar plays an important role in plant hormone physiology. First, binding of IAA to a sugar increases by 400-fold the rate at which the hormone moves from the seed (source) to the shoot where it performs its growth function. Second, the binding and the freeing of the hormone from the sugar provide the plant with a way to control the level of the active form of the hormone. Third, binding of IAA to a sugar protects the IAA. These findings have provided researchers in the field with a new approach to help answer the ultimate mystery of how this hormone acts in promoting plant growth and development.

Ethylene, a gaseous hormone under physiological conditions, affects many aspects of plant growth, development, and aging, but its elusive nature makes investigation of its role difficult. Yang, in his study of ethylene biosynthesis, has discovered a compound that is the immediate precursor of ethylene. This compound, known as ACC, is a solid under normal conditions. Furthermore, Yang's laboratory has characterized the enzyme, ACC synthetase, that promotes the conversion of an earlier compound, S-adenosylmethionine, to ACC. This significant breakthrough has made possible both fundamental and applied research in ethylene biochemistry and physiology. For example, the plant stress response to waterlogging is an increased production of ethylene in the shoot. Yang found that under such conditions ACC synthesis in the roots greatly increased, with the ACC then transported upward to the shoots where it was readily converted to ethylene.

Another research emphasis in this area concerns the ability of food legumes to fix nitrogen biologically and their capacity to accumulate abundant seed protein. Such traits are obviously attractive at a time when nitrogen fertilizer costs are high and there is an increasing demand for protein. Timothy C. Hall at the University of Wisconsin, Madison, has studied the fundamental mechanisms of seed protein synthesis and the factors regulating protein quantity and quality. This research required the development of new techniques and criteria to follow rapidly the effects of genetic changes on protein quality and seed protein accumulation.

F. A. Bliss, a collaborator of Hall's, developed new soybean strains having high-biological-value seed protein and placed them in field trial. Hall and Bliss used information and techniques developed during basic investigations on the mechanisms of protein synthesis, regulation, and control of amino acid composition to develop protein with specific nutritional properties. With the new techniques of genetic manipulation, it should be possible to obtain legume seed protein approaching the biological quality of meat protein.

However, many plant proteins having the proper amino acid content for a high-biological-value protein cause weight loss rather than weight gain when fed to animals. The weight loss occurs because seed protein is often accompanied by seed constituents that are inhibitors of digestion. For example, the enzyme trypsin is essential in the digestive process. It digests protein and releases amino acids that are then absorbed from the intestinal tract. However, in many seed proteins there are enough trypsin inhibitors present to prevent digestion. The protein passes through without the nutrient amino acids being released and absorbed. Other inhibitors affect the absorption capacities of the cells lining the gut.

Obviously, then, the genetic engineering of high-quality protein and seed yield capacity is not enough. Attempts to alter protein composition must consider the consequences in the broadest sense of nutritional modification. Rather than modifying the toxic action of the seed protein through chemical or heat processing, Hall believes that basic information should be developed on the mechanisms controlling synthesis and on the reasons for poor digestibility of some proteins. Then it will be possible to develop and implement optimum methods for genetic alteration.

Cell Membranes in Information Transfer

Recent advances in cell and molecular biology have emphasized that gene expression can be affected by external changes at the cell surface. A major research effort is directed towards determining how such changes or signals are received and transmitted to the nucleus and describing the changes in macromolecular structure that occur when such gene expression is activated or repressed.

Lewis Kleinsmith at the University of Michigan has described an experimental system that offers a unique opportunity to study signal transduction from the cell surface to the nucleus. This system consists of the early developmental stages of the sea urchin, whose surface is covered with cilia (minute hairs). Structures called microtubules, which are composed of protein subunits known as tubulin, form an integral part of these surface cilia. The amount of tubulin messenger RNA (mRNA) that originates in the cell nuclei of sea urchin embryos can be measured. Cilia can be removed by a chemical treatment that allows the embryos to survive and eventually regenerate new cilia. The amount of embryonic tubulin mRNA increased dramatically shortly after ciliary removal, confirming activation of genes in the nucleus by events occurring at the cell surface.

A second example of gene activation through events occurring at cell surfaces involves a polypeptide called epidermal growth factor (EGF). EGF can stimulate quiescent cells in culture to divide. Since such cells are impermeable to large molecules such as EGF, the stimulus for proliferation was believed to be due to cell surface pertubation caused by binding of EGF to the plasma membrane.

Using isotopically labeled material, Robert W. Holley, Nobel Laureate at the Salk Institute, and other investigators have shown that EGF is first bound to receptors on the cell surface, then internalized, and finally partially degraded. Whether receptor occupancy is sufficient to stimulate DNA synthesis or whether internalization of EGF is necessary for stimulating genome replication is still unclear. However, maximal stimulation of DNA synthesis occurs when 70 to 85 percent of the cell surface EGF receptors are occupied.

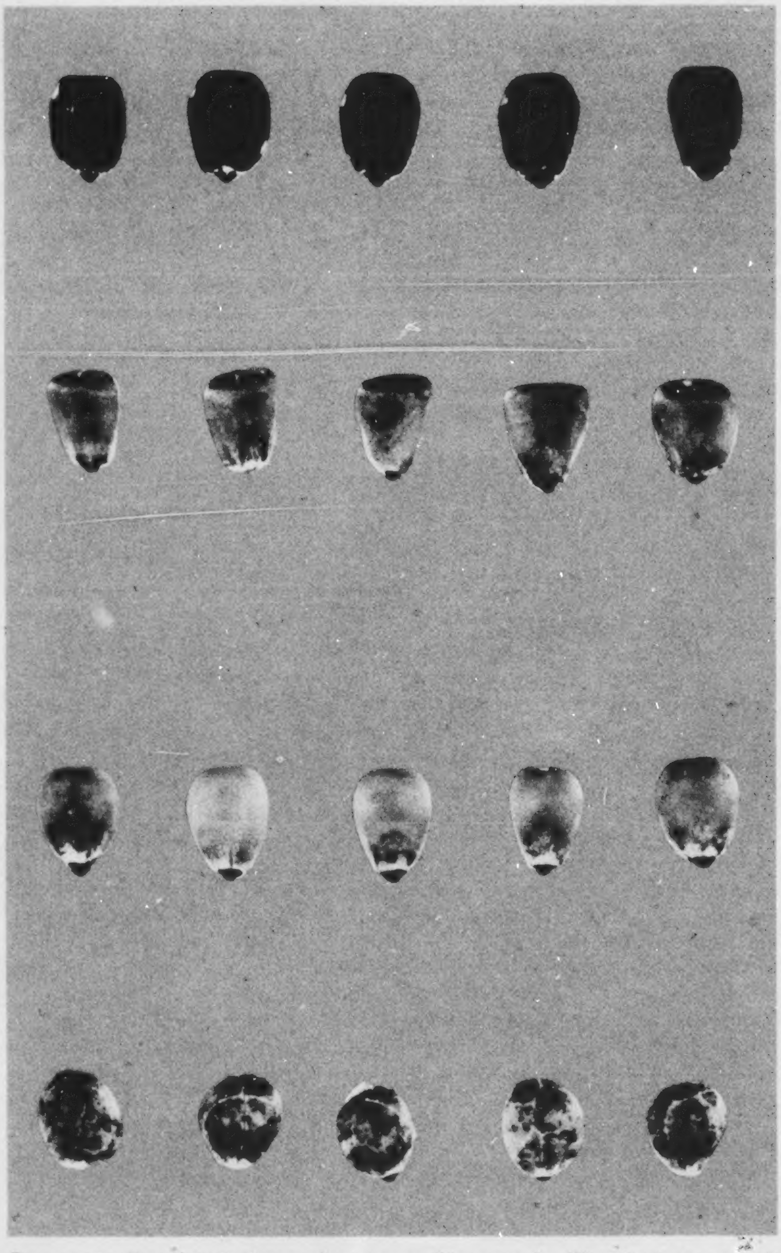
Still a third approach is being taken by Clara Szego at the University of California, Los Angeles. Studies of how steroid hormones act provide information on how stimuli for gene activation are conveyed from the cell surface to the genome. Because they are soluble in lipids (which are present in high concentration in cell membranes), steroid hormones were thought to have free entry into their target cells and to thus travel to the nucleus and chromatin via a carrier called the cytosol receptor. By a combination of cytochemical and biochemical techniques, Szego has demonstrated that cell surface receptors for these hormones exist and are indeed internalized and sequestered by liposomes, which then serve to translocate the hormone to the nucleus.

The Dynamic Genome

Transposons are small segments of DNA that can move from one chromosome to another. They have been found in bacteria, corn, and animals. Their discovery has changed our thinking about the stability of DNA, the genetic material. The mechanisms by which some of these "jumping genes" move have been demonstrated by recent experimentation.

Using the bacterium *salmonella*, Melvin Simon and colleagues at the University of California, San Diego, were one of the first groups to demonstrate that the position and orientation of a specific fragment of DNA determine whether a gene is expressed. In a series of elegant experiments, Simon showed that a fragment of DNA adjacent to one of the known genes could be inserted into the genome (the bacterial chromosome) in either of two different orientations. Oriented in one direction, the bacterium produces one type of flagellum (an appendage for propulsion); but when oriented in the other direction, another type is made.

In another kind of experiment, Nancy



Corn genes. Kernals in the top row have a normal bronze color. When the bronze gene is missing (second row), no pigment is produced. But a similar effect (third row) results if a controlling gene element moves into position near the bronze gene and prevents it from being expressed. Finally, if an activator gene element is present, it will displace the controlling gene and permit the bronze gene to function. The fourth row shows kernals in which this displacement has occurred in some, but not all, of the cells, resulting in partial expression of color. Such experiments demonstrate the movement of genes in plants in a manner similar to that in bacteria and viruses.

Kleckner and associates at the Massachusetts Institute of Technology have used the phenomenon of antibiotic resistance to demonstrate how translocons are involved in *in vivo* genetic engineering. They have shown that DNA containing a segment (or gene) that encodes for resistance to antibiotics can be transferred from plasmid (small rings of bacterial DNA containing only a few genes) to virus and back to bacteria. Such translocations directly alter genome expression as well as the arrangement of genetic material. These translocatable elements apparently function as powerful tools with which bacteria perform evolutionary "genetic engineering."

Some of the best evidence that DNA segments also move in organisms higher than viruses and bacteria was derived from the original studies in 1940 of Barbara McClintock at the Carnegie Institution of Washington laboratory in New York. More recently, Oliver Nelson at the University of Wisconsin has been examining these "controlling elements" to increase our knowledge of the mechanism of their effect on gene function. He and his colleagues have characterized an enzyme (glucosyltransferase) which is encoded by a mutable gene (bronze) and which interacts with a controlling element (*DS*) in corn. In some cases the enzyme is normal but is not synthesized at the normal time in plant development. In other cases the enzyme itself is altered in its amino acid sequence.

Nelson is currently in the process of cloning the bronze gene, with and without the *DS* element, in order to determine at the DNA level how the gene and controlling element are structured. This work is invaluable to our understanding of gene function in plant cells.

Another example of gene rearrangement has turned up in recent experimentation on immune systems. Higher organisms have the ability to manufacture an immense diversity of antibody molecules—specific proteins that attack specific antigens that may invade the body. These various antibody molecules consist of two regions: a sequence of amino acids that is constant among related antibodies, and a second, variable, region, that gives each antibody its specificity.

The group of genes responsible for the production of antibodies presents an important biological problem. That is, what genetic mechanism is responsible for the diversity of antibody molecules? Leroy Hood and his associates at the California Institute of Technology have shown that, in mammals, a rearrangement of the DNA occurs during development. These rearrangements are thought to be fundamental to the molecular events that commit the antibody-producing cell to the synthesis of a specific antibody.

Hood's group has focused on the largest protein chain found in the antibody molecule. The group of genes responsible for producing this chain is comprised of an unknown number of gene segments coding for the variable regions and at least eight different gene segments coding for the constant regions. They have shown that, for a specific antibody-producing cell, a particular antibody is made through an association of a particular variable gene with a particular constant segment. Using a technique developed by Edward Southern at the University of California, San Francisco, called a "Southern Blot," they have evidence that the DNA rearrangement in variable and constant regions occurs during the differentiation of antibody-producing cells.

Environmental Biology

Populations of individual plants and animals make continual adjustments to their environments. Taken *en masse*, however, these adjusting populations make up an environment—or at least its biological component. NSF's program in environmental biology supports studies of both.

On the single-population scale, the precision of the adaptation of each of the 1.5 million known species has always been a research focus—though it is being pursued with ever-increasing sophistication. And within the past decade, new techniques have revealed unsuspected genetic heterogeneity among individuals within populations and among semi-isolated populations of the same species.

It is evident that more complete understanding of the adaptation for survival, particularly in fluctuating environments, requires simultaneous pursuit of objectives once studied separately. Since the structural, physiological, ecological, behavioral, and genetic aspects of adaptedness appear dynamically linked, these must be examined simultaneously in carefully integrated research. Economy dictates, however, that such intensive efforts be focused on carefully selected model populations, such as the four *Drosophila* (fruitfly) species living in decaying cacti of the harsh Sonoran desert and soil-dwelling nematodes that attack food crops. Both are discussed on the following pages.

On the biological macroscale, it becomes increasingly important to understand how ecosystems and populations function. If the information base can be enlarged sufficiently, decisionmakers may be able to apply the knowledge to the protection of the environment and of individual plant and animal species. This information could guide regional development efforts as well.

The tropics are a particularly pressing problem. Research activities in tropical biology address serious impacts resulting from large-scale development and change in the tropical forest biome. Two phenomena are occurring throughout the tropical region. Forests, which form the major type of vegetation over vast parts of Latin America, Africa, and Asia, are being rapidly cut for timber, for fuel, and to provide land for agriculture and cattle raising. Removal of forests has, in turn, caused the extinction or reduction in the range of tropical plants and animals. Scientists predict that this biome and its flora and fauna will essentially be destroyed within the next 50 years.

If these estimates are correct, then the world biological community is faced with a crisis of unprecedented magnitude. It becomes important to collect and identify the floras and faunas of tropical regions before they are extinguished. It is equally important to evaluate the impact of such broad changes of the biota on the atmosphere and hydrosphere.

Understanding of the global carbon dioxide exchange, for instance, requires information from tropical as well as temperate areas. These data are inadequate at present. Similarly, our understanding of acid rain problems in newly industrializing tropical areas is inadequate. For each case—global carbon dioxide, acid rain, and faunal-floral extinction due to tropical deforestation—these problems focus on areas outside of the continental United States, yet their impacts can be global.

Research on floras and faunas of tropical areas is supported in a variety of tropical countries. Balancing these classical studies are the sophisticated ecosystem investigations that address questions of the dynamics of essential nutrients in forests, plantations, and cultivated fields. Nutrient cycling studies are of special interest, largely because of the concern over the exchange of carbon dioxide between soil, vegetation, water, and the atmosphere. These studies typically are carried out in cooperation with scientists from the host country. They may also involve foreign graduate students who work with the U.S. investigators to learn techniques and procedures current in this country.

Soil Nematodes

Soil-inhabiting nematodes, a significant part of the biotic world, include some major plant pests. In fact, cyst and root-knot nematodes (*Meloidogyne* and *Heterodera*) are considered by agriculturists to be one of the five most important plant pathogens in the world. These organisms are extremely interesting biologically, and some of their characteristics revealed in a recent study may be a key to controlling their damage to crops.

The nematodes reproduce by a complex series of mechanisms involving both parthenogenesis (asexual reproduction) and modification of chromosome number. These characteristics have made it difficult to classify, identify, and relate the species to one another, although considerable research has been devoted to the problem of nematode biology by workers in the United States and abroad.

In the most comprehensive work to date, Anastasios Triantaphyllou at North Carolina State University has studied species of cyst and root-knot nematodes from the viewpoints of morphology, physiology, cytology, and DNA composition. He maintains a stock collection of 700 populations of plant parasitic nematodes for use in his research. He and his collaborators have shown that extensive changes in reproductive pattern and chromosomal structure have accompanied differentiation of these nematodes into new species; these changes are associated in turn with differences in behavior of the nematodes, especially with their specificity for particular plants.

The most damaging species seem to be those that have combined parthenogenesis with losses of chromosomes or with chromosome multiplication (polyploidy). A key observation is that these atypical species survive poorly in natural habitats but are highly successful under cultivated crop conditions. They thrive in the artificial and relatively recent environment provided by modern agricultural activities.

Triantaphyllou's research is an excellent example of systematic biology—study of a group of organisms that offers a challenge as a taxonomic group. In this case the findings allow a better understanding of relationships of organisms that have come to have a significant impact on agricultural activities. The fact that one can track the history of the parasites and relate it to current farming practices and problems may be important in planning future studies of the ecology and control of these important organisms. Because current agricultural patterns may be directly responsible for nematode damage to plants, continued efforts to discover resistant crops and to plant them in strategic crop rotation should reduce their harmful impacts on food supplies.

Nutrient Cycling in Ecosystems

NSF's ecosystem studies program supports many different ecosystem-level, nutrient-cycling projects. As a result, ecologists have increased significantly their understanding of soil, plant, and animal processes, and nutrient transfer. This new information, much of it guided by development of community- and system-level models, also is proving invaluable for management-related programs. The Environmental Protection Agency, the Department of Energy, and the U.S. Department of Agriculture are using the information produced by basic research to set agency management policies. Acid precipitation, global carbon cycles, and plant productivity are only a few of the issues to which the NSF-supported basic studies relate.

Individual watershed studies have been designed to account for all inputs and outputs to and from a system, especially of nitrogen, phosphorus, and other nutrients. Research has been carried out over a broad area, ranging from the tundra and black spruce forests of subarctic Alaska to the neoequatorial tropical forest lowlands of Venezuela. Temperate forests have been studied in the conifer-dominated systems of Oregon, the mixed forests of New Hampshire, and the southern deciduous forest of North Carolina.

Some studies have depended on the cooperative support of more than one Federal agency and, in the case of the tropical forest project, on the cooperation of a foreign government and several international agencies. The USDA/-Forest Service and USDI/Bureau of Land Management have been the primary cooperators on U.S.-based projects. The fundamental objectives have been to describe the basic pattern of nutrient dynamics of the watershed ecosystems, to identify and quantify the main control on nutrient flow, and to investigate their responses to perturbations.

The perturbations to which the systems have been subjected are both natural and man-induced. Natural perturbations include fire in Alaska and insect defoliation in North Carolina. Man-induced perturbations include forest cutting in Oregon, New Hampshire, and North Carolina, modern agriculture in southeast Georgia, and primitive agriculture (cutting, burning, planting) in Venezuela.

A fundamental observation emerging from these studies is that natural systems conserve nutrients, especially nitrogen, and that managed systems tend to lose nutrients in relatively large amounts. For example, in the forest floor—with its accumulated organic debris, surface roots, and fungi—the upper layer of soil releases nutrients slowly, by decay processes.

The upper soil zone is active biologically since it is generally well buffered against extremes of temperature and moisture and provides nitrogen and phosphorus to microorganisms and plant roots. The mechanisms by which this zone responds are both physico-chemical and biological. Physico-chemical mechanisms include the immobilization of nutrient ions by their attachment to complex compounds and by their adsorption on organic (decaying matter) and inorganic (primarily clay) particle surfaces. Biological mechanisms include ingestion and incorporation into biomass by many species of multicellular and unicellular fauna and flora and absorption by roots and mycorrhizal fungi with translocation to other plant parts. The widespread studies are just now compiling evidence from which processes in various systems, including the tropics, can be compared.

The upper soil zone is essentially self-maintaining but depends on the annual input of organic debris and interactions among the diverse plant, animal, and microbial species. As long as the zone is not radically disturbed, it can serve the system very efficiently as a "valve," controlling the losses of nutrient elements and conserving them for internal use. If it is severely damaged or removed, or if it encounters extraordinary inputs of nutrients, it "leaks," allowing measurably higher concentrations of nutrients to show up in groundwater and drainage streams.

Very hot fires not only destroy the accumulated organic matter and its biota, but they leave behind a highly soluble mineral ash; certain forest harvesting or clearing methods disturb or remove large portions of the upper soil zone; and canopy insect outbreaks can overload the zone with soluble nutrients by their input of waste material. Any single event of this sort can seriously impair nutrient-conserving mechanisms. Two or more together, such as tropical slash and burn agriculture, can essentially destroy the system by releasing thousands of years of accumulated nutrients in one or a few cropping seasons.

Recent international meetings have been held to assess our understanding of nutrient cycling, particularly of nitrogen and carbon. For carbon the main question is how much is being pumped into the atmosphere and biosphere from burning fossil fuels and widespread clearing or change of various plant communities, particularly in tropical and temperate forests. For nitrogen, there is general concern about mineralization and dimineralization processes, the release of nitrate compounds into atmosphere and water, and the release of ammonia and nitrous oxide into the atmosphere.

All of these have profound effects on biota and structural surfaces, but there is sufficient evidence about the total impact. One of the main emphases of ecosystem researchers is to ensure that well balanced programs, including field, laboratory, and modeling approaches, be designed.

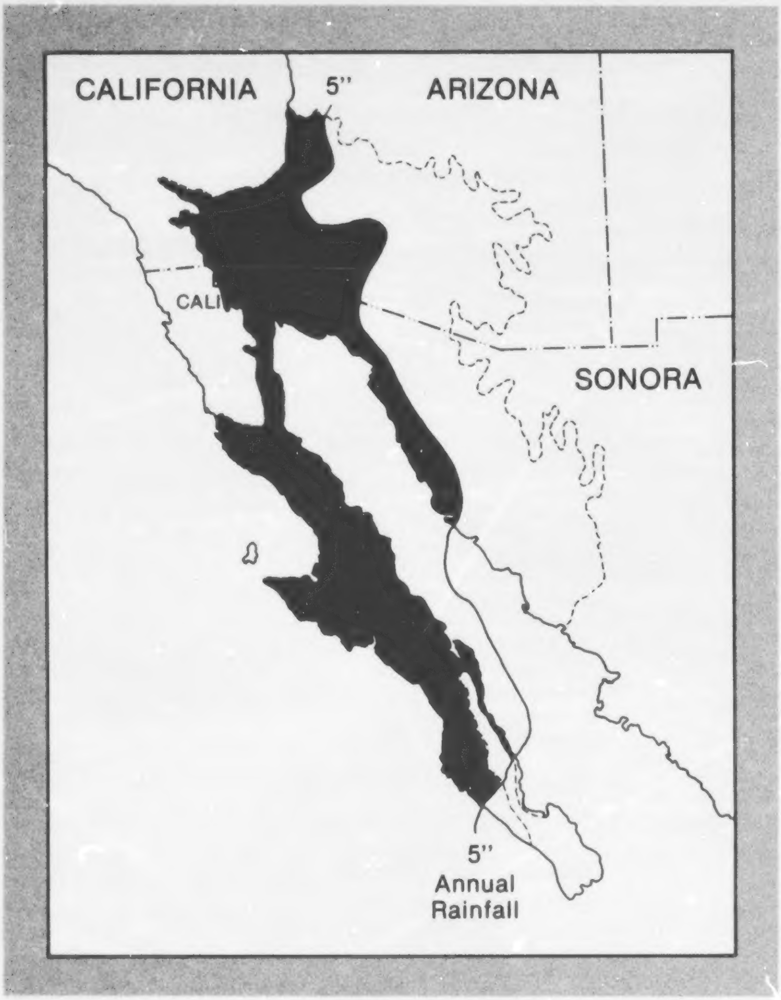
Ecological Genetics of Cactus-Dwelling Drosophila

How the genetic constitution of the individual relates to its environment and how the genetic information in the species is modified as the environment changes are two of the major questions of population biology. Answers to them often involve integration of different scientific disciplines. A good example of a successful integration of genetics, ecology, and chemistry in a concerted population study is being conducted by William Heed and Henry Kircher and their colleagues at the University of Arizona. The research concerns *Drosophila* (fruit fly) species that live in several kinds of large, decaying cacti (e.g., saguaro, organ pipe, and senita) in the Sonoran Desert.

To understand the ecological relationship between the *Drosophila* and the cacti and the present distribution of Sonoran *Drosophila*, the evolutionary history of both the *Drosophila* and their host plants must be clarified. Four species of *Drosophila* are native, or endemic, to the most arid parts of the Sonoran Desert. These four probably first occupied the desert at different times; they are not closely related to each other. The limited number of *Drosophila* species may be due to the unfavorable climate coupled with the failure of other *Drosophila* to evolve the capability to breed in the large columnar cacti. By synthesizing data on *Drosophila* with information available on the biogeographical history of columnar cacti, the scientists are developing an evolutionary perspective on the events leading to the present distribution of the arid desert *Drosophila*.

Living cactus tissue is unsuitable for use as food and larval habitat by *Drosophila*. Rather, a number of structural and chemical modifications, occurring after the plant is damaged, are necessary. Injury, often caused by freezing, exposes succulent tissues that become infected and are decomposed by bacteria. Following this, saprophytic yeasts become established in the rot pocket. These yeasts produce vitamins, proteins, and other chemicals that both adult and larval stages of *Drosophila* require in their diet. In addition, adult *Drosophila* feed directly on the yeasts.

Usually the rot involves several pounds of cactus tissue, which can support several thousand *Drosophila*. In three of the four fruit fly species, eggs are deposited in the rot and larvae develop there. In the fourth species, however, eggs are laid and



Population biology. Scientists are studying the four species of *Drosophila* that live in association with decaying cacti in the driest Sonoran Desert to learn more about how species adapt to changing environments.

larvae develop in the soil moistened by fluids from the rot.

There are several factors that determine the mixture of *Drosophila* and yeast species on any particular cactus. One of these is the chemistry of the cactus itself. Kircher, a natural-products chemist, has made detailed analyses of the three major host cacti. The three hosts do, in fact, differ significantly in chemical make-up, with organ pipe being most complex, saguaro least, and senita intermediate. The species of *Drosophila* and yeasts supported by any particular host are corelated to the relative chemical complexity of that host. For example, *Drosophila pachea* is found almost exclusively on senita since it is actually dependent on a sterol produced by the cactus. Moreover, other *Drosophila* are excluded from breeding in senita by compounds they cannot tolerate.

Another aspect of the interaction among the cacti, yeasts, and *Drosophila* that determines *Drosophila* distribution is the effect of the chemical composition of the rotting cactus. This type of interaction occurs in the response of different *Drosophila* to the ethanol produced by yeast decomposition. Specifically, *Drosophila mojavensis* demonstrates an increased longevity when ethanol is available in the environment. This change in longevity occurs in samples of this species from different parts of its range, but most importantly, the response varies differentially in concert with the occurrence of a specific yeast.

Changes in genetic makeup of the *Drosophila* species have tentatively been linked to variations in environmental characteristics. For instance, geographic patterns of genetic variation in an enzyme, alcohol dehydrogenase (ADH), which plays a role in the metabolism of ethanol, covary with patterns of host cacti distribution and with acidity and temperatures of rot pockets of the different hosts. This covarying pattern suggests that individuals with different molecular forms of ADH metabolize ethanol with different degrees of efficiency. This efficiency would also change under different physical and chemical environments of rot pockets.

Individuals possessing the optimal form of ADH for specific conditions would have an advantage over other individuals possessing other molecular configurations of ADH under those conditions. This same situation would occur at the species level among those possessing different forms of ADH. As a result, differential survival and reproduction would occur among individuals and species, leading to *Drosophila* that are better adapted to the rot pockets utilized as larval and adult feeding sites. This system is a model for enzymes in many other species, both plant and animal. Current research concentrates on understanding the effect and relative importance of the host-plant preference, chemical and microflora composition of the rot pocket, and climate on genetic variation in alcohol dehydrogenase.

Behavioral and Neural Sciences

The behavioral and neural sciences continue to generate exciting projects and significant results. This is especially true in neuroscience, which has grown rapidly during the past decade. Progress in neurochemistry, membrane research, neural development, sensory processes, and the study of simple invertebrate nervous systems is especially noteworthy. Neurochemists have focused on the role of peptides in the brain and the identification and characterization of new transmitter substances. The membranes of nerve cells have been shown to be intimately involved in the transmission of nerve impulses and the encoding of sensory information. Simple invertebrate animals have been used increasingly to study neural development and plasticity. This has provided a major opportunity for achieving significant advances in understanding the role of specific individual neurons in behavior.

Research in the chemical senses—taste and smell—is being invigorated with the genesis of a new society: *The Association for Chemoreception Sciences*. This new scientific organization came about as an outgrowth of an NSF-sponsored conference held in 1976; its first very successful scientific meeting was held in spring 1979.

Cognitive science focuses on the human ability to gain and use knowledge and to process information. Research on the process of reading and comprehending text and on the development of cognitive abilities and the acquisition of language has been especially active. The approaches of neuroscience and cognitive science come together in such areas as the neurophysiology of speech. Research relating brain function to cognitive function constitutes a small but growing interdisciplinary research focus.

Research on the individual and social behavior of human beings and other organisms utilizes both experimentation and systematic observation in the laboratory and the field. Major advances have been made in understanding the means by which birds and insects recognize locations and orient themselves to reach distant targets. Among the environmental cues that appear to be important for both insect and avian navigation are the Earth's magnetic field and the positions of the Sun and stars. A magnetic substance, magnetite, discovered in the abdomens of honey bees, in the heads of homing pigeons, and in bacteria, may play a key role in the ability of animals to orient and navigate.

Although the social behavior of human beings is complex and difficult to study, the relationship of such studies to improvement in the human condition is crucial. Communication is one aspect of social behavior that is the subject of considerable study. While much of our communication is verbal, involving spoken or written language, nonverbal communication, through facial expressions, gestures, eye-contact, and body movements or posture, also occurs. And the propensity for nonverbal communication, if not inborn, develops early in life. Recent research, for instance, shows that even during the first few months of life children are capable of showing discrete and readily recognized emotional expressions, including joy, surprise, sadness, anger, disgust and fear.

Anthropological research integrates biological, physical, and social science approaches toward understanding human behavior. Its scope in time and space is immense. Research varies from studies of modern civilizations to studies on the emergence and development of the human species. As a result of cooperation between paleoanthropologists and natural scientists, research seeking the origins of humanity has increased dramatically. In 1978 a conference on human origins was held at NSF. As recommended at this conference, NSF is now planning a coordinated effort on human origins research.

Chemical Transmitters in the Brain

Research seeking to identify the chemicals that transmit signals between nerve cells in the brain and to determine how they act has revealed surprising and potentially useful new insights. Several previously unsuspected chemicals, including hormones or hormone-releasing factors, are involved. Further, as a consequence of work with invertebrate organisms whose neurons are extraordinarily large, the list of neurotransmitter substances probably will have to be extended to include new candidates of still another kind.

Until recently, it was considered that hormones were hormones and neurotransmitters were neurotransmitters, with their chemical properties and definitions barely overlapping. For example, traditionally, vasopressin has been defined as a hormone, having its physiologic effect on blood pressure and water reabsorption. Now, evidence suggests that vasopressin also may be a neurotransmitter that modulates nerve cell activity and affects behavior. Data from the experiments of Gary Kozlowski at the University of Texas and Gail Hostetter at the University of Oregon Medical School indicate that certain nerve fibers that terminate in the brain contain vasopressin in a transport form. Additionally, administration of vasopressin reverses a behavioral effect of damage to a specific part of the brain and influences the performance of research animals in certain laboratory tests.

These findings suggest that vasopressin-containing fibers terminate on those brain structures that may function in processing neuroendocrine events or in predisposing the animal for subsequent neuroendocrine events. This finding is even more intriguing when coupled with the recent conclusions that neuron-generated releasing factors for several peptide hormones also have neurotransmitter action.

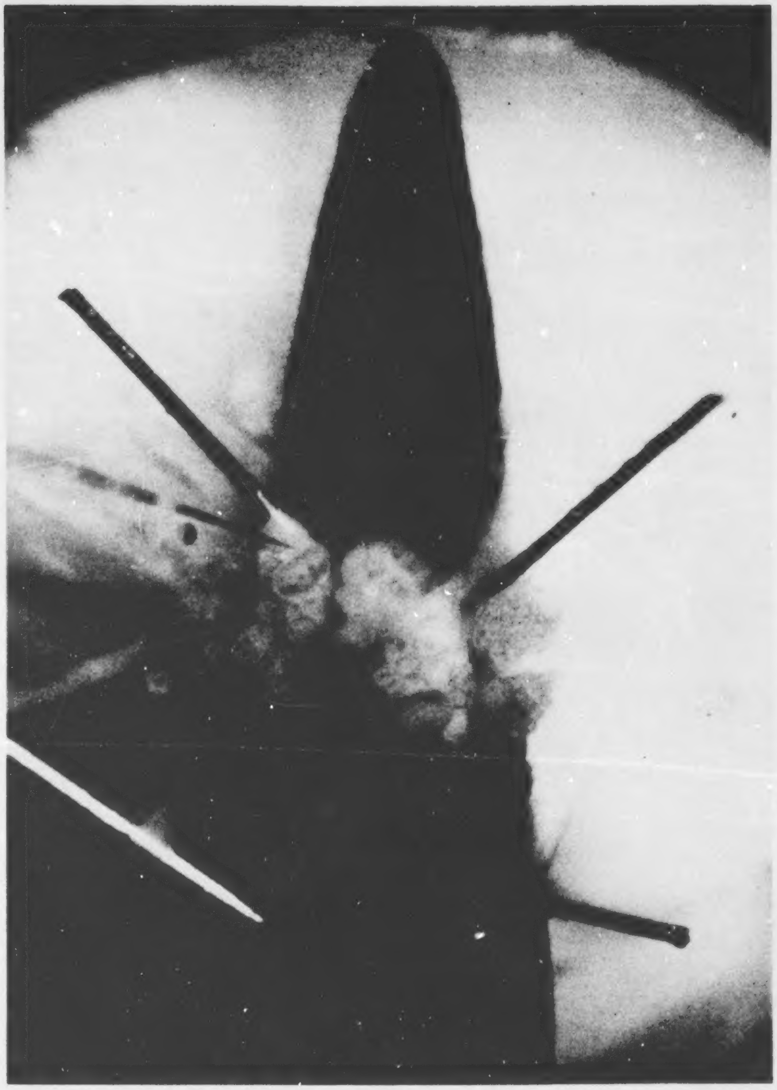
That peptides may be neurotransmitters, or at the very least, modulators of neuronal activity, is significant for two reasons. First, it is thought that addictive opiate and other drugs may act at the same neuronal receptor sites as some of the peptides. Second, if certain peptides are neurotransmitters, it opens the door to an immense new range of possible neuroactive substances, since the number of combinations and subtle variations in structure of these peptide molecules is very large.

A related finding comes from work by Richard McCaman at the City of Hope National Medical Center in Duarte, California, and Daniel Weinreich at the University of Maryland. They have developed techniques that permit critical testing of individual neurons in marine mollusks. McCaman has shown that at least 75 percent of these neurons do not use any of the classically recognized neurotransmitters. Among their findings is confirmation of the presence and role of histamine—best known for its role in allergic reactions—as a neurotransmitter. This is a role of histamine for which there has been only indirect evidence for many years.

Land-Use Patterns in the Valley of Mexico

How human communities perceive, organize, and manage the different components of their environment is gaining increased attention from cultural anthropologists. Research on environmental knowledge in many traditional cultures, including studies of botanical knowledge, of medical beliefs and practices, and of the classification of animal species, indicates that this knowledge is often detailed, precise, complex, and ordered into logical and systematic categories. This realization has led, in turn, to a refocusing of ecological studies—from how environment affects human societies and cultures to how the study of particular environments can be improved by learning from traditional societies.

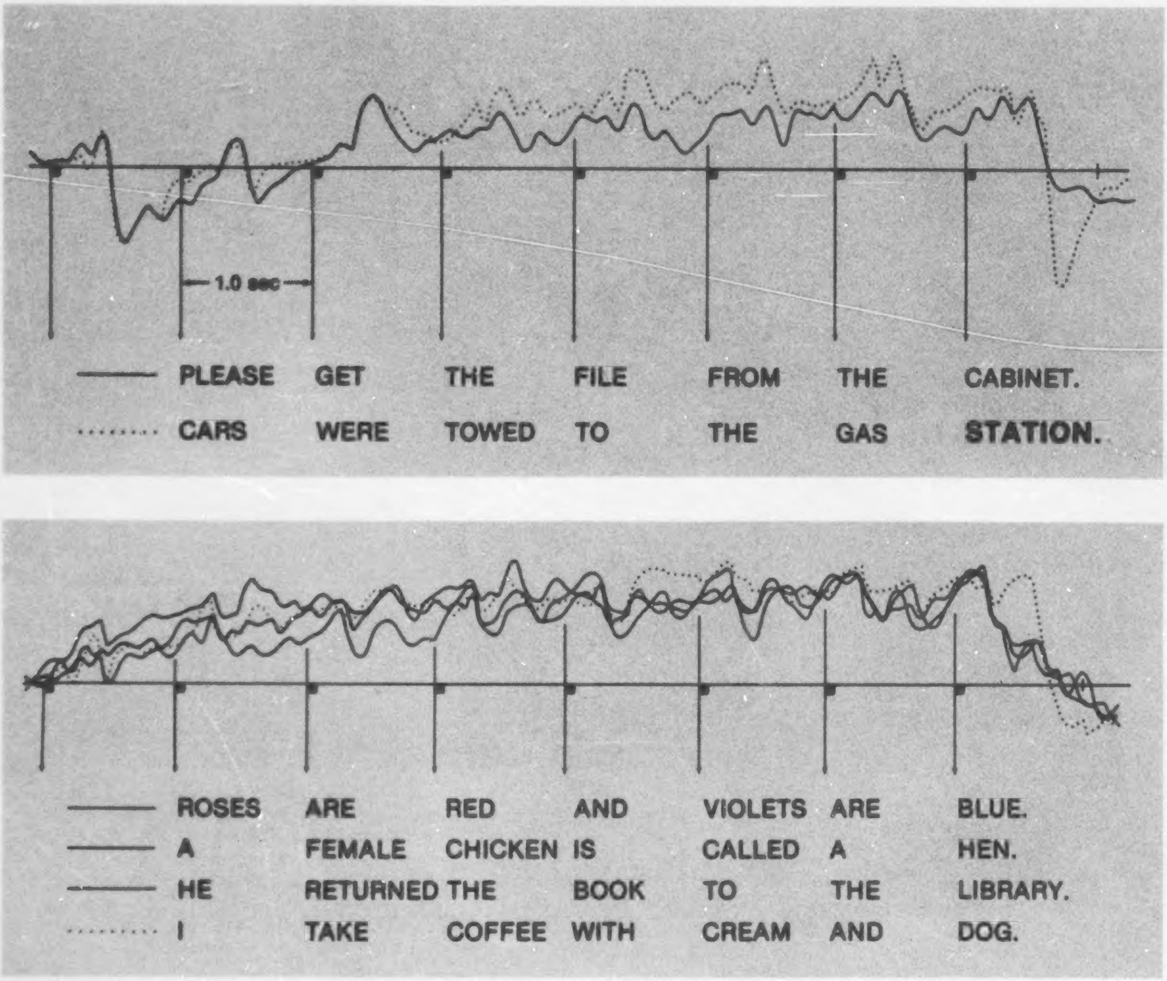
Barbara Williams of the University of Wisconsin is studying the human perception and classification of soils over many generations in the Valley of Mexico. Williams' research employs a variety of methods, including the study and translation of historical records, interviews with current inhabitants of the valley, and analysis of soil types. A major source of data is two unpublished pictorial manuscripts (codices), written in the 16th-century Nahuatl language. They record information on population size, size of landholdings, and soil quality as perceived by the local population for 16 localities in the eastern part of the valley.



Measuring brain activity. The brain of the tropical sea slug is characterized by its extraordinarily large (more than one-millimeter-diameter) and identifiable neurons. As seen here, a fine electrode has been inserted into one of these neurons of a functioning brain (the large pins hold it in place under the microscope). This direct access to a neuron is a unique experimental technique for studying electrical and molecular processes that control brain function.

Since the geographic area to which one of these manuscripts pertains has been precisely identified, contemporary and archaic landholding practices can be compared, particularly in terms of size and quality of landholdings in relation to household size and position in the community. Using such evidence as field shapes and dimensions, soil types, and the positioning of aqueducts, stream beds, and canals, Williams is developing a 16th-century soil map with enough detail to determine persistence and change from the 16th century to the present. The map will also permit estimates to be made of the carrying capacity of land in pre-Conquest times.

In many communities in the Valley of Mexico, traditional agricultural practices persist. To pursue the comparison, villagers were asked to identify the soil types in their fields, describe the soil characteristics, and compare them with other local soil types. Soil samples were then taken for laboratory analysis. Local perceptions and laboratory results were compared. Local soil classifications are linked closely to soil management and technology. Some aspects of the Nahuatl classification system, Williams concluded,



Unexpected words. Brain-wave recordings of people encountering unusual stimuli are used in studies of how language is processed. A simple deviation (above)—the word *station* in larger type than the rest of the sentence—produces a wave form (identified as "late positive") comparable to that accompanying simple nonreading tasks. But the large negative form caused by a semantic deviance ("I take coffee with cream and dog") shows a different brain response, which may bear on the question of language as a distinct mental activity.

appear to be based on actual agricultural potential as a primary attribute, while others are based on the concept that soil acquires fertility as a result of human intervention.

Cultural aspects of environmental classification and perception take on additional dimensions for traditional societies; the quantity and quality of the soil resource is directly related to the land's carrying capacity and thus to population size. Further, insofar as soil quantity and quality are a basis of wealth in an agricultural society, an unequal distribution of the soil resource is both a cause and a consequence of political, economic, and social stratification.

Assessment of soil resources and tenure rights thus is fundamental to understanding the functioning of agrarian societies and, increasingly, to the implementation of resource management of modern agricultural development programs. A practical application of Williams' work, for instance, is in facilitating communication between agricultural extension personnel and farmers who use traditional methods.

Neurophysiology of Language

An intriguing question is whether, from a neurophysiological standpoint, the use of language is a "special" mental activity, qualitatively distinct from other sorts of cognitive activity, or whether language is similar to other sorts of cognitive processes. Robert Galambos of the University of California, San Diego, has been using electroencephalographic techniques to relate electrical activity of the brain to the process of using language.

Several recent experiments have utilized the following procedure: Subjects silently read different seven-word sentences, presented briefly on a screen, and brain potentials evoked by the words are analyzed as a function of the position of the words in the sentence. The experiments were designed to determine the manner in which components of the brain's activity reflect an occasional change in some characteristic of the last word of the sentence. In some sentences the characteristic varied was physical: a change in the type face or size for the last word. In others the deviation was semantic, i.e., the last word would not make sense in the context of the sentence.

The occasional occurrence of a word of a discrepant type face or size resulted in the enhancement of specific, identifiable positive components of the brain's electrical activity. This effect of a physical change is similar to that found in other cognitive tasks that don't involve language. The effect of the semantic manipulation, however, was a surprise: Semantic deviance is accompanied by a large *negative* wave whose amplitude is proportional to the degree of semantic absurdity. Thus, meaningless statements, such as "I take coffee with cream and dog," are associated with larger negative waves than such unexpected statements as, "I take coffee with cream and milk." Unexplained statements in turn show enhanced negativity when compared with the expected statement, "I take coffee with cream and sugar." The discovery of this negative wave, which had not previously been noticed and was quite unexpected, provides evidence that the language processing activities of the brain are in fact "special" and distinct from other mental activity.

Social and Economic Science

In changing the name of this program area and restructuring it during fiscal year 1979, NSF has tried to clarify the nature and scope of its activities in social science research. While references to "physics" and "chemistry" rarely cause any misunderstanding about their subject matter or research concerns, the term "social science" does. It is used in different contexts and by different individuals to refer to a wide range of activities, many of which—unlike those supported by NSF—are not undertaken for scientific purposes, do not employ scientific methods, and do not add to our store of basic knowledge about our social environment.

Like other fields of science, social and economic science has an internal disciplinary structure, employs specialized methods and techniques, and produces knowledge that ultimately has applications to real-world problems. For example, responses to the energy problems that currently plague this country are limited more by economic, political, and social factors than by technological factors. Analyses have repeatedly emphasized conservation as an essential element in both the short- and long-term easement of energy shortages. Yet effective efforts in this direction lag because significantly less is known about the behavior of individuals or groups than about the behavior of atoms or molecules. While energy is a ubiquitous problem on a physical or biological level, it is America's most salient problem on a social and economic level.

NSF's programs were developed on the premise that strengthening this country's scientific capability for understanding social and economic behavior, organization, and change is vitally important to the national interest. The pressing task before social and economic science is to develop better methods and more comprehensive data resources so that research findings are more valid, reliable, and generalizable. Therefore, NSF's programs have concentrated on the continued improvement of statistical methods for the analysis of data.

One important new technique, latent variable methodology, is discussed in detail in the following section. Another promising one is "quasi-experimental analysis," developed largely by Donald T. Campbell of Syracuse University. These methods seek to create partial substitutes for laboratory controls, where possible, and to identify specific threats to valid inference where laboratory control is impossible.

Dependable conclusions that rule out plausible rival explanations are scarce in the social sciences. Yet their importance is clear and warrants the heavy emphasis given to attempts to specify the kinds of biases and ambiguities associated with available methods and to develop new methods that permit identification of real-world cause-effect relationships.

The development of large, detailed data bases to which new methods can be applied is another area of concentration. Detailed data are needed to verify findings based on small-scale observation. Although important insights may be gained through such observation, well grounded generalizations are dependent on large-scale tests.

Statistical data produced by Government agencies as part of their operating responsibilities constitute an important resource for large-scale social and economic research, but these data are not always readily available for research purposes and frequently are inadequate. Therefore, NSF supports projects that make these data more accessible to social and economic scientists and provides support for selective additions to the store of Government-produced data.

Two major projects provide selective additions. One is the National Election Study, a biennial survey of a national sample of the American electorate designed to provide detailed data on political participation and electoral behavior. The other is the General Social Survey, another biennial survey of a national sample of adult Americans designed to provide continuing data on social conditions, behavioral responses to changing conditions, and ensuing attitudes and expectations. The survey focuses on variables not covered in other data collections. Because it includes a sophisticated system of encoding public information relating to environmental, demographic, industrial, and social characteristics of small geographic areas, hypotheses about the relationship between changes taking place at the society-wide level and changes taking place in the subjective experience of individual citizens can be tested.

The General Social Survey is an important social science resource that is having a major impact on social science research and training. It is also being used by several Federal agencies for mission-oriented purposes.

Advanced techniques and adequate data require a third element to fulfill the goal of increasing the store of basic knowledge about the workings of our social and economic system: the development of appropriate theory and concepts leading to testable hypotheses. This is the third aspect of NSF support and a most important one. Advances in thinking on rational expectations, the dimensions of political participation, organizational behavior, and on-location models have improved our understanding of the processes involved in economic growth and social organization. Together, these three components—theoretical development, analytic tools, and data resources—constitute the core of contemporary research in social and economic science.

Progress in the development of social science knowledge has been irregular and uneven partially because these three components have been progressing in different ways and at different rates. An important function of the NSF effort in social and economic science is to facilitate the coordination of the three components and thereby contribute to the growth of knowledge that will be useful in foreseeing the ramifications of policy alternatives on major social and economic trends.

Latent Variable Methodology

A continuing social issue has been the degree of social, economic, and occupational mobility in society. Analyses have produced contradictory findings because of inadequacies of data and methods. Clearly a number of factors interact in an extremely complex way to affect individual and group outcomes. In the early to mid-1960's, researchers estimated that the contribution of schooling to the growth of the U.S. economy was on the order of 12 to 15 percent and that investment in formal education returned a corresponding yield in the lifetime income of individuals of about 6 percent.

The immediate and most important challenge to these estimates of the economic contribution of schooling hinged on the issue of ability. One estimate, in 1964, claimed that as much as 40 percent of the observed income differentials could be due to the positive correlation between native ability and the levels of schooling achieved by different parts of the population. Other analyses produced contradictory findings.

Over the past decade NSF's economics program has supported new research on estimating the economic returns to formal schooling and on untangling these returns from the contributions of factors such as native ability, family background, discrimination, and nepotism. The recent availability of large microdata sets, which provide information on family members and other individuals over time, has opened up rich opportunities for testing hypotheses in this crucial area. At an aggregate level, also, there are new data that offer potential for resolving the long-standing issue of the effect of education on economic growth. The full exploration of these data, however, has awaited the development of new statistical techniques to adjust for biases in the handling of missing variables.

Owing to the work of a number of econometricians, it is possible now to handle these missing variables, the so-called "latent variables," explicitly rather than either assuming that their influence is negligible or depending on the use of faulty observable proxies. The new statistical approach requires that the missing variable (such as ability) affect more than one dependent variable (such as schooling and family background). The basic idea is that such a variable causes similar biases (proportional to each other) in different equations, which in turn permits the estimation of most of the coefficients of interest.

Zvi Griliches and Gary Chamberlain

at Harvard University have refined this "latent variable" methodology and have applied it to a variety of data sources needed to estimate the income-schooling relationship in the presence of an unobserved ability factor. Based on these studies they have concluded that ability is important in determining the ultimate economic success of individuals, but it appears to work largely through its effect on schooling rather than independently. The bias in the estimated economic returns to formal education, due to correlations of schooling with ability, is much smaller than expected. They find the biasing effect of ability to be only about 10 to 15 percent as compared with the earlier estimate of 40 percent. The rate of return to schooling and ability combined continues to be estimated at the appreciable level of 6 percent, of which ability may account for roughly 1 percent.

The results of the new microanalytic work of Chamberlain and Griliches also reinforce the earlier findings of Griliches. The rising schooling level of the labor force has a substantial effect on the growth of the U.S. economy. These calculations indicate that fully one-third of the remarkable growth that took place in overall productivity from 1940 to 1970 stemmed from the concurrent increase in the national level of schooling. Additional empirical analyses are projected, but the broad implications of the completed research for education and development policy already are plain, as are the wide variety of other issues for which this statistical approach will be important.

OLEDO

Science Education

4

To meet its legislative mandate for improving science education at all levels, NSF supports programs to foster wider and more effective participation in science. These activities are aimed both at improving the education of individuals who may be planning science-based careers and at enabling the nonscience public to function more knowledgeably in a society dependent upon science and technology.

Science education in the Nation's schools, colleges, and universities continues to face pressures that are threatening its effectiveness in meeting those goals. Teachers and professors find it increasingly difficult to bring important new science findings to their students in the classroom and the laboratory. Costs of education are escalating rapidly, and enrollments are dropping. There is public concern over the quality of instruction. Despite efforts to date, underrepresentation of disadvantaged minorities, women, and the physically handicapped in science remains a problem. In a different arena, the general public finds it difficult to know how to respond to issues like Three Mile Island, the Love Canal, the energy crisis, the presence of potential carcinogens in the environment, or the reported decline in the Nation's technological competitiveness.

To meet this set of diverse needs, NSF's Science Education programs have established four complementary objectives: (1) provide a basic understanding of the nature, power, and limitations of science to as many students as possible, (2) improve the access of adults to scientific knowledge and information needed in dealing with important public issues, (3) foster the participation in science of previously underrepresented groups, and (4) generate the new knowledge necessary for the improvement of science education.

Practically, this means that some programs assist institutions in improving their own capabilities in science education. Other programs are directed towards identifying, motivating, and supporting a limited number of highly qualified individuals interested in scientific careers. Research and development programs are important in producing the understanding, materials, processes, and technologies necessary to make science education more effective and efficient. Finally, to reach wide audiences—both adult and child—efforts outside of the formal educational system are necessary.

Science Education Resources Improvement

Science education resources improvement programs help colleges and universities to improve undergraduate science instruction and to provide decisionmakers in elementary and secondary schools with information about recent developments in instructional materials, educational practices, and research findings related to science education. In addition, NSF supports minority institutions and academic centers to strengthen their science education capabilities and to encourage tal-

Table 5
Science Education Resources Improvement
Fiscal Year 1979

(Dollars in Millions)

	Proposals		Awards	
	Number	Amount	Number	Amount
Comprehensive Assistance to Undergraduate Science Education	311	$55.60	72	$13.52
Undergraduate Instructional Improvement	1,971	27.55	435	6.40
Information Dissemination	116	3.19	36	1.03
Minority Institution Science Improvement	61	10.21	39	4.91
Resource Centers for Science and Engineering	1	2.99	1	2.74
Total	**2,460**	**$99.54**	**583**	**$28.60**

SOURCE: Fiscal Year 1981 Budget to Congress—Justification of Estimates of Appropriations (Quantitative Program Data Tables).

ented persons from underrepresented ethnic minority groups and from low-income families to pursue careers in science.

There are currently six separate but related activities aimed at assisting institutions to provide quality science education programs at all educational levels. The emphasis in each of these programs is to expand opportunities for participation to all types of institutions, especially those colleges with limited resources and experiences in dealing with NSF.

Comprehensive Assistance to Undergraduate Science Education (CAUSE)

The primary objective of the CAUSE program is to strengthen the undergraduate science education at 2- and 4-year colleges and universities. Efforts are aimed at improving the quality of the Nation's science education at the undergraduate level and enhancing the capability of institutions for self-assessment, management, and evaluation of their science programs.

The program encourages broad, integrated projects dealing with a comprehensive set of science education activities. The 72 recipients of 1979 CAUSE awards include 16 2-year colleges, 30 non-Ph.D degree-granting institutions 23 Ph.D. institutions, and 3 consortia. The projects reflect each institution's unique efforts to improve undergraduate science education.

More than half of this year's projects have a major emphasis on the use of computers in the undergraduate curriculum; nearly a third involve individualized instruction. Other dominant themes are faculty development, facility improvement, science for nonscience majors, and use of audio-visual media. The following paragraphs give some specific examples illustrating this diversity.

Institutions of all types, sizes, and geographic locations are increasingly providing experiences in computer science for their undergraduates. For example, computer literacy projects will be conducted at Loras College in Dubuque, Iowa, and Wheaton College in Norton, Massachusetts. A science education computer network will be developed at the Claremont Colleges in California. At Alabama A&M in Normal, Alabama, a comprehensive modular approach to computer instruction will be instituted. Microcomputers will form the core of undergraduate science education instruction at Pima Community College in Tucson, Arizona; Mississippi Industrial College in Holly Springs; Manhattan College, Bronx, New York; and the University of Oregon in Eugene.

The improvement of science instructional facilities is another important support category. These range from general improvements such as those planned at Bethune-Cookman College in Daytona Beach, Florida, and the establishment of learning centers at South Georgia College in Douglas, Georgia, to a greenhouse project at Southern Oregon College in Ashland, Oregon, and a field station development at Dutchess Community College in Poughkeepsie, New York.

A final example of the diversity of project activities: Several awardees will concentrate on improving instructional techniques and audio-visual equipment and materials for use in science courses. Florida Institute of Technology will restructure biology laboratory instruction using audio-visual tutorial units, as will Donnelly College in Kansas City, Kansas. At Prairie View A&M University in Texas freshman mathematics students will use self-paced instructional materials. Developmental and physiological psychology courses at Indiana University will utilize self-instructional systems, while at Fresno City College in California individualized instructional components will be developed for a mathematics laboratory.

Undergraduate Instructional Improvement

The common purpose of the local course improvement (LOCI) and instructional scientific equipment (ISEP) programs is to enable institutions to respond rapidly to relatively small-scale undergraduate science instructional problems to enhance teaching by encouraging science faculty to pursue imaginative ideas in upgrading their instruction.

Projects focus on undergraduate instruction in science, including courses intended for science majors, nonscience majors, those preparing for careers as teachers of elementary and secondary school science, or students preparing for technological careers. Awards go to widely differing types of public and private institutions, including the undergraduate components of universities, predominantly minority institutions, 2-year colleges, and 4-year liberal arts colleges.

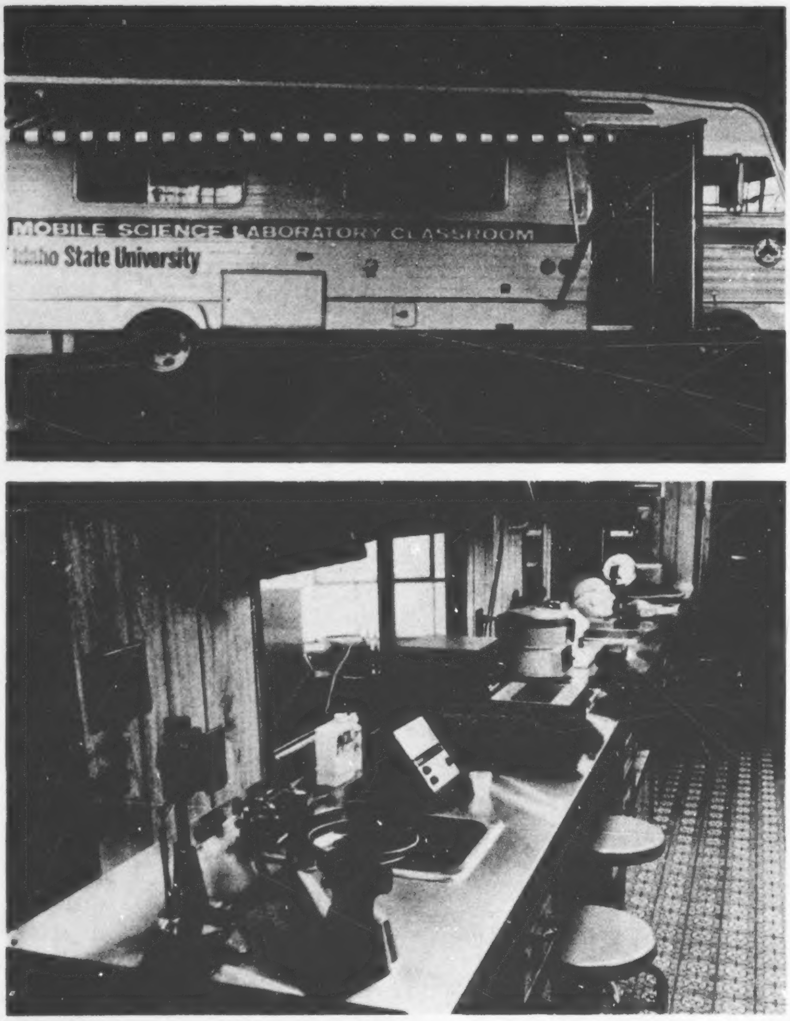
In an effort to make the results of NSF-supported LOCI and ISEP course and laboratory improvement projects available to others, a book entitled *A Guide to Undergraduate Science Courses and Laboratory Improvements* was published by NSF in 1979 and distributed to nearly 3,000 institutions of higher education in the United States.

Local Course Improvement (LOCI)

LOCI awards stimulate rapid introduction of the results of scientific and educational research into the undergraduate curriculum and provide science faculty with the opportunity to develop teaching innovations. In fiscal year 1979 151 awards were made to 136 colleges and universities in 43 States and Puerto Rico. The maximum award was $25,000, and all awards required an institutional contribution.

Three topical areas illustrate the broad spectrum of activities supported through the program: computer-oriented projects; projects aimed at prospective pre-college science teachers; and specialized, technical course improvements.

Projects involving computer technology are wide-ranging in their differing uses of the computer in the instructional setting, the types of institutions conducting such projects, and the diversity of the student audiences for which they are in-



CAUSE project. Idaho State University is using this mobile laboratory/classroom to bring college courses in biology and environmental science to rural communities.

tended. Computer literacy for engineering students at Florida Atlantic University in Boca Raton and the use of computer graphics for learning pre-calculus mathematics at the University of California, Santa Cruz, are illustrative of this range. At Milliken University in Decatur, Illinois, computer training is provided for behavioral science students, while Central Wesleyan College in Central South Carolina and the University of Texas at Austin are using computers in introductory biology classes.

Courses geared to the needs of preservice teachers of elementary and secondary school science are being developed at a number of schools; all levels (elementary, junior high, and senior high) are represented as well as a range of subject-matter areas: physical science, economics, computer science, and mathematics.

Examples of specialized course improvements include solar energy at the State University of New York at Binghamton, a communications satellite supplement for technical physics students at Muskingum Area Technical College in Zanesville, Ohio, and laboratory studies of petrology at the University of Vermont in Burlington.

Instructional Scientific Equipment

These projects permit improvements in science instruction through the acquisition of new laboratory and instructional equipment. The objective is to provide relevant "hands-on" experience for undergraduate students in science and engineering laboratories. In fiscal year 1979 284 awards were made to colleges and universities. In each case the Foundation grant—a maximum of $20,000—was matched by at least an equal amount of institutional funding.

The University of Rhode Island, Kingston, is establishing a modern plant cell biology teaching laboratory to be shared by two departments. Students of plant cell structure and metabolism are learning new techniques that form the basis of research in agricultural productivity.

At Ocean County College in Toms River, New Jersey, science and liberal arts students can acquire increased computer literacy through the introduction of videodisc technology. The project, using videodisc as a source of graphic illustration, provides about 500 students each year with an improved computer-aided instruction program.

Reed College in Portland, Oregon, is augmenting student research and instruction in chemistry through the use of computer terminals with graphic capabilities. The computer clarifies classroom topics, introduces new material, extends laboratory data analysis capability, and introduces computer-based drills.

At Mississippi College in Clinton, students use a circuit-board microprocessor system as a hands-on tool to learn both hardware and software aspects of this increasingly important technology.

Engineering laboratories at Bradley University in Peoria, Illinois, are replacing experiments that use full-sized components with those using model-sized structures and components. Eight student stations are being built where students can have hands-on experience in measuring forces, strains, and displacements produced by static loads and forces. The performance of full-sized systems will be predicted from these data.

Information Dissemination for Science Education

Now in its third year of operation, this small grants program helps school administrators, subject-matter specialists, teacher-leaders, school board members, and other decisionmakers in State and local school systems to obtain information about instructional materials and practices prior to selection.

Thirty-six awards in fiscal year 1979 for conferences and workshops enabled such school decisionmakers to become familiar with the large variety of science instructional materials, practices, and technologies currently available for use in elementary and secondary schools. In some projects information on current research results in pre-college science and mathematics education was presented to participants along with potential classroom applications.

It is interesting to note the increase in the number of awards addressing two of NSF's special emphasis areas: science for the early adolescent and science for handicapped students. All but one of the 36 awards are targeted in whole or in part at the early adolescent educational level. Six awards and approximately 11 percent of program activities are aimed at the special problems of science for handicapped students. As in previous years there continues to be considerable interest in the dissemination of information about alternative curricular materials and information on computers and hand-held calculators.

This year's projects include six regional conferences held in Ohio for junior and senior high school mathematics educators under a grant awarded to Ohio University. These conferences provide direction on problem solving, alternative curricular materials, and the use of hand-held calculators in the secondary school classroom. East Carolina University is conducting four workshops to inform educators throughout North Carolina about the goals and organization of several science programs designed specifically for mentally and physically handicapped students. The Wisconsin Academy of Science, Arts, and Letters is working with State science supervisors and university personnel to conduct regional conferences in Iowa, Minnesota, and Wisconsin on new ideas of intellectual development and their implications for helping students to develop reasoning ability while learning science. The University of California, Berkeley, is arranging conferences on calculator-assisted mathematics materials, teaching ideas, and strategies including calculator hardware and commercially available instructional materials.

Minority Institutions Science Improvement Program

This program effects long-range improvement in science education at 2-year and 4-year institutions with predominantly minority enrollments (American Indian, Alaskan Native, Black, Mexican-American, Puerto Rican, or other ethnic minorities who are underrepresented in science and engineering). Program objectives are to increase the number of minority students graduating with majors in the sciences, mathematics, or engineering; to improve the quality of their preparation for graduate work or careers in science; and to improve the competitiveness of minority institutions for other Federal funding programs.

In 1979 39 awards were made. The largest number of awards (23) was in the *institutional* category in support of comprehensive projects of up to 3 years' duration. The average award size was $185,000. One *cooperative award* was made to an *ad hoc* group of institutions for the improvement of computer-assisted instruction at approximately 30 minority institutions. For the third year, small *design* grants were available for institutions to help them develop long-range science improvement plans. The two design grants funded this year bring the total number to nine during the 3-year period.

A new major effort in 1979 was *special* projects of up to 2 years' duration and $50,000 for focused activities to implement improvement goals outside the usual comprehensive institutional format. Six regional proposal development workshops and seven other special projects were funded.

The following descriptions are illustrative of the kinds of projects in each category. Our Lady of the Lake University in Texas is conducting a 3-year institutional project to develop a computer science program for training faculty and preparing computer-based curriculum materials in the natural and social sciences. A 3-year cooperative project administered by Bennett College and North Carolina A&T State University involves approximately 30 institutions in North and South Carolina and Virginia. Science faculty at these institutions are being trained in the use of computer-assisted instruction and are developing instructional materials to be shared with all participating institutions. A 12-month design grant to Biscayne College, a predominantly Cuban-American institution in Florida, is assisting the college in conducting a science needs assessment and in developing a long-range science improvement plan based on this assessment. Finally, a special grant to Talladega College in Alabama supports a 2-year program in which prominent scientists who are actively involved in research will make approximately 90 2-day visits to minority institutions. The scientists engage in a variety of activities, including lecturing and conducting seminars on their research, teaching mini-courses, and providing students with information on career opportunities in the visiting scientists' fields. Also, at the six regional proposal development workshops, science faculty representatives from minority institutions are gaining skills in proposal development and review, project monitoring, and data collection and recordkeeping techniques.

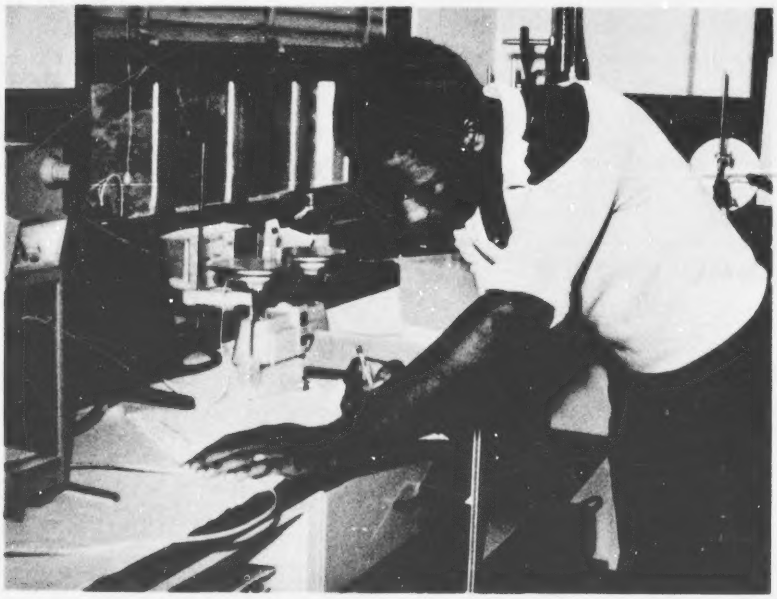
Resource Centers for Science and Engineering

This program, a successor to the earlier minority centers for graduate education in science and engineering program, increases participation in science and engineering by minorities and persons from low-income families. As in fiscal year 1978, the Foundation was authorized to establish a single resource center in 1979. Criteria for selection were that it: (1) be geographically located near one or more population centers of minority groups or low-income families; (2) support basic research; (3) serve as a regional resource in science and engineering; and (4) develop joint educational programs with nearby pre-college and undergraduate institutions enrolling substantial numbers of minority students or students from low-income families.

Atlanta University received the first award as a result of the first competition. The next two ranking proposals from that competition were invited to submit a joint proposal for 1979. These two institutions, the University of New Mexico and New Mexico State University, subsequently received support in the amount of $2,742,000 for a Southwest Resource Center.

The Southwest Resource Center is addressing itself to graduate and undergraduate education, 2-year colleges, public school education, and community affairs as they relate to increased science awareness and to the development of young scientists and engineers. The University of New Mexico and New Mexico State University will be joined by at least 15 educational institutions and two scientific laboratories in their efforts to increase both science awareness and the number of scientists and engineers among the Mexican-American and American-Indian communities in New Mexico, western Texas, Arizona, and Colorado.

Activities within this center will be conducted primarily through two major components. Among the activities proposed for the *pre-college and community programs* are teacher/counselor workshops, science fairs and exhibits, visits to scientific laboratories, development and dissemination of career guidance materials oriented to Mexican-Americans and American Indians, educational television programs, regional conferences focusing on minority issues in science,



Increasing participation. Activities at the Atlanta Resource Center for Science and Engineering involve the educational process at all levels. An opportunity to work with a research scientist brought an older student (left) to the Center for a summer program; a young student (right) takes part in the Saturday Science Academy for grades 3-8.

and a visiting scientists program. The *academic and research programs* will support faculty and student research projects, provide a limited number of postdoctoral fellowships and faculty-student research internships, assist participating institutions in their minority science faculty and student recruitment efforts, and provide counseling and tutoring services for minority science students.

Science Education Development and Research

Due to rapid changes in science and society and the vital interactions between them, science education itself must be continually modified through development and research. Both are needed to introduce new knowledge into the educational process, to prepare people for new science-related tasks and problems, to translate scientific knowledge into a form that can be understood and learned, to capitalize on new insights into the ways we learn, and to assure that people will be able to cope with and participate broadly in our technologically base society.

Development and research are not separate processes; they interact in complex ways. Development not only provides new curriculum materials and new ways to teach, but also generates new situations with new information for use in educational research. Research in science education gives us new ways of viewing the process of learning—the way we develop scientific skills and knowledge.

Fiscal year 1979 represented the first year for these newly reconstituted science education research and development programs as cornerstones of NSF's major role in a strong national effort in science education research and in attacking science education problems of the early adolescent. Other program priorities in FY 1979 were the use of technology in science education, science literacy, problems at the interface of science, technology, and society, and the continuing education of scientists and engineers. Activities also included development support aimed at the problem of national productivity and research on cognitive processes and the structure of knowledge.

As part of a long-range planning process, a series of reports was commissioned in 1978 to formulate a comprehensive research and development agenda. The second in the series, *Technology in Science Education: The Next Ten Years* (SE 79-57, published in 1979) consists of analyses and recommendations concerning technology and science education for the decade ahead. Similarly, an earlier report, *Early Adolescence* (SE 78-75), includes perspectives and recommendations on science and mathematics education for the early adolescent.

Table 6
Science Education Development and Research
Fiscal Year 1970

(Dollars in Millions)

	Proposals		Awards	
	Number	Amount	Number	Amount
Development in Science Education	152	$30.78	53	$ 8.18
Research in Science Education	167	19.62	40	3.83
Total	**319**	**$50.40**	**93**	**$12.01**

SOURCE: Fiscal Year 1981 Budget to Congress—Justification of Estimates of Appropriations (Quantitative Program Data Tables).

Development in Science Education

The development in science education (DISE) program supports the design, field testing, and dissemination of innovative teaching and learning models and materials for science instruction at any level of education. In addition to continued support of several major projects, the DISE program emphasized five special areas: science for the early adolescent; improving access to careers in science; science technology and society; new knowledge and new skills—education for productivity; and technology as applied to learning. This last area included a special solicitation for proposals and support of two projects to design, build, and demonstrate an interactive computer-controlled videodisc system for science education. Following are brief descriptions of these areas and examples of projects supported.

It is disturbing to note that most U.S. citizens receive very little formal science instruction after their junior high school or early adolescent years. Because this is a time often ignored in terms of special emphasis in science instruction, NSF supports projects dealing with pre-service and in-service education of teachers of middle and junior high science. Projects designed to provide junior high school students with information about various fields within science and the related careers are also supported.

By way of illustration, a project at Central Michigan University is designed to produce, evaluate, and disseminate a set of audio-tutorial units in science for the inner city student. Another project, at the National Wildlife Federation, involves preparing high-quality environmental science curriculum materials for middle and junior high schools to develop knowledge of relationships in the natural environment. Also included among the awards this year are efforts in outdoor/informal education such as the Lawrence Hall of Science project on physical science activities in out-of-school settings for early adolescents and their families.

Eight projects in improving access to

Concept-based modules. Using materials developed at the University of Washington to help prepare academically disadvantaged students for college science studies, these lower division undergraduates investigate circular motion by experimenting with an air puck fastened to a pivot with rubber bands.

careers in science were aimed at students ranging from middle school to college. The projects encompass a variety of educational activities for both in-school and out-of-school settings. Two projects are addressed to the special needs of women, three to the special needs of minorities, and three to the needs of both groups. These projects focus on such themes as relating science and mathematics subject matter to scientific careers, providing appropriate role models, and developing general problem-solving and reasoning skills. Three projects will develop material for in-service training of junior high and high school teachers.

In one project aimed at increasing access to careers, Lillian C. McDermott at the University of Washington, working to increase the ability of minorities to participate in mainstream college science courses, has developed a set of instructional materials for lower division undergraduates. These materials, useful in physics, chemistry, and the physical sciences, emphasize both concept formation and reasoning development. They are designed to provide flexibility in length, choice of subject matter, and options for sequencing in courses in which they are used.

The connections between science and society are seldom emphasized in education at any level. For the most part, the education of scientists and engineers fails to deal in any depth with the humanistic aspect of their work or to raise the difficult issue of the social responsibilities of science. Conversely, education in the nonscientific professions is deficient in its neglect of science, and the general education of most citizens prepares them poorly to deal with the science-related social issues and the value problems of the day.

Barry Hyman, working through the American Society for Engineering Education, is using a case study strategy to convey an understanding of public policy to undergraduate engineering students. For four summers, engineering students chosen through a nationwide competition will participate in a public policy internship program in Washington, D.C. Based on their work, case studies will be developed and disseminated widely for use in undergraduate engineering curricula. By the fourth summer, support of the program will be taken over by engineering societies and industry.

In another award, older people, who are rarely exposed to science courses, will participate in a special education program in science and society. The program, at the University of Colorado at Colorado Springs and Colorado College, has the long-term goal of developing a model to encourage older people to attend regular college science courses for credit. This project extends and complements the informal education project supported at the same institution by NSF's public understanding of science program.

The NSF focus, new knowledge and new skills—education for productivity, supports the revision of curricula so that scientifically trained personnel can better contribute to appropriate technological development and, through increased productivity, to the country's economic strength and quality of life. The curricula may be for undergraduate, graduate, and

Field trip. Scientists from the University of Colorado discuss plate tectonics and the geology of the Pikes Peak region with a study group of senior citizens.

continuing education; the projects, usually based in universities or professional groups, are encouraged to collaborate strongly with industry and with nonacademic laboratories.

A project with David M. Himmelblau at the University of Texas at Austin is producing modules for 2,000 topics which give explanations, references to best practice, or study guides that will be formulated for electronic transmission and retrieval by computer. The system of materials will be structured so that specialists can contribute short pieces for teaching new developments without having to rewrite the equivalent of a whole text. Fulfillment of these objectives will be tested in about a dozen industrial and university programs.

The increased use of computers, particularly microcomputers, has increased the demand for people trained in digital systems engineering, which is a combination of electrical engineering and computer science and engineering. Thomas A. Brubaker at Colorado State University is studying ten leading research institutions, both industrial and academic, to identify and develop prototypes of useful materials for teaching digital systems engineering. The goal of the project is to reformulate and combine traditional principles around several thousand generalized engineering techniques which can be retrieved and learned for specific applications.

Projects concerned with the use and technology for science education include the exploration of innovative applications of technology for instruction, the development of materials on using technology as a tool of science, or the development of materials to study the technology itself. Most projects are based on the use of computers, sometimes in conjunction with other devices. For example, several projects supported incorporate the use of graphics to improve instruction. To explore the education potential of the new videodisc technology, Robert Fuller and his colleagues at the Univesity of Nebraska at Lincoln are developing a low-cost approach for the videodisc in physics instruction.

Techniques used by meteorologists in analyzing and reporting the weather are based on the computer analysis and graphical display of weather data collected by satellite. Atmospheric sciences education will begin to incorporate some of these methods as a result of work by Donald Johnson at the University of Wisconsin supported jointly by NSF's atmospheric sciences program and DISE program. Because similar needs exist in other environmental sciences, these systems should be useful beyond departments of meteorology.

A number of projects are concerned with continuing education for nonacademically employed scientists and engineers. An example is a project conducted by the Utah State Board of Regents, through which industries and universities cooperatively develop science-related training programs for industry. Entitled "Restructuring Science Education for Flexibility, Occupational Preparedness, and Industrial Alignment," the project is now completing its period of NSF support; it has obtained $200,000 in local contracts in 1979. In addition to providing technical updating for industrially employed scientists and engineers, the project is notable for its impact on increasing university-industrial cooperation.

Research in Science Education

Scientific knowledge changes, as do the contexts in which it is taught. These changes have implications for public issues, technology, and individual decision-making. The processes by which people may be helped to acquire what they need to know are not well understood. The research in science education (RISE) program assists in creating and organizing a body of fundamental knowledge that can be used to improve the quality and effectiveness of science education for a wide spectrum of individual needs. RISE supports both research evaluation and synthesis, and empirical research. Within these two categories, projects were supported in 1979 on science education for

Education for productivity. In the past year more than 2,000 engineering students at Rensselaer Polytechnic Institute used a refresh graphics system as part of their course work. Michael Wozny, the principal investigator on this DISE project, is coordinating selected educational activities across the Nation which use computer graphics as a design tool.

the early adolescent, science for women and minorities, technology in science education, and science literacy. In addition, the program, jointly with the National Institute of Education, sponsored research on cognitive processes and the structure of knowledge.

Of the RISE awards this year, 20 are directed to research in science or mathematics education for the early adolescent. Some 13 of the new RISE awards focus on understanding the underrepresentation of minorities and women in science and science-related careers, while three RISE projects are concerned with the continuing education of scientists and engineers. The RISE awards continue to show an increase in collaboration of investigators from a variety of scientific disciplines with research workers in science and mathematics education research. Examples of RISE projects supported in 1979 follow.

Experts on early adolescence cite the need for the collection and organization of extensive demographic information on the early adolescent. A newly supported project directed by Herbert Walberg at the University of Illinois at Chicago Circle will attempt to demonstrate the feasibility of using data from the National Assessment of Educational Progress (NAEP) for secondary analysis purposes. Over the past 10 years NAEP has gathered and reported information on the knowledge, skills, and attitudes of American 9-, 13- and 17-year olds. The University of Illinois group will collaborate with research teams at Northern Illinois University, the University of Minnesota, and key NAEP staff. Another project, "School, Family, and Individual Influences on Commitment to and Learning of Science Among Adolescent Students," directed by Ronald Simpson at North Carolina State University, is trying to determine how interest and competence in science develops in the early adolescent student.

A research team led by Alma Lantz at the Denver Research Institute has been interested in the pervasive belief that mathematics acts as a selective barrier to science careers for women and that early decisions made to opt out of mathematics courses foreclose opportunities. In a comparative study of junior high school level males and females, these researchers are studying influences on student choices in taking (or not taking) the first optional courses in mathematics.

Widespread concerns have been expressed about potentially detrimental effects of the use of calculators on children's mathematics abilities. A team of investigators led by Grayson Wheatley at Purdue University has been studying the initial impact of calculators in elementary school mathematics with 1,500 students (grades 2-6) in 50 classrooms in Indiana, Iowa, Michigan, Missouri, and Ohio. Their year-long study, which tested students in basic facts of addition, subtraction, multiplication, and division, in mathematics concepts and attitudes, indicates: (1) that no measurable detrimental effects can be ascribed to calculator use; (2) that children have a high positive attitude towards calculator use; and (3) that children learn to use calculators quickly and perform computations much more successfully than their counterparts with no calculators.

What do mature adults (ages 50-70) learn of science policy issues from television—specifically, from viewing selected NOVA programs on public television? Robert Gagne and his coworkers at Florida State University are seeking answers to such questions in a study that is expected to shed light on how specialized instruction can help to increase scientific literacy in adult Americans.

At the Massachusetts Institute of Technology, a group of investigators from the fields of psychology and the philosophy of science, led by Susan Carey, is investigating the parallels between conceptual development during childhood and conceptual change in the history of science. They will analyze the development of the child's concepts of weight, volume, and density, in comparison with the differentiation of these concepts in the history of science, and will study the historical development of the concepts of heat and temperature in order to pursue the comparison further.

Scientific Personnel Improvement

Increasingly, the solutions of societal problems depend on the application of science. For that reason, strength in science education, to assure an adequate number of highly trained personnel, is an important national asset. Thus, the objectives of the scientific personnel improvement programs are: to identify and

Table 7
Scientific Personnel Improvement
Fiscal Year 1979

(Dollars in Millions)

	Proposals		Awards		Number of Individuals Supported
	Number	Amount	Number	Amount	
Faculty Improvement Programs	1,398	$34.49	387	$10.03	16,316
Minorities, Women and Physically Handicapped	185	4.95	81	2.36	9,280
Student-Oriented Programs	940	15.50	319	5.42	6,240
Fellowships and Traineeships	5,144	45.03	1,744	15.26	1,910
Total	**7,667**	**$99.97**	**2,531**	**$33.07**	**33,746**

SOURCE: Fiscal Year 1981 Budget to Congress—Justification of Estimates of Appropriations (Quantitative Program Data Tables) encourage scientific talent; to assist in maintaining high standards and quality training of students and professionals in the sciences; and to stimulate more participation in the sciences by minorities, women, and the handicapped.

Four program areas contribute to these objectives: (1) faculty improvement at the pre-college and college levels; (2) minorities, women, and the physically handicapped at the junior high school level and above; (3) student-oriented programs at the high school and undergraduate levels; and (4) fellowships and traineeships at the graduate and postdoctoral levels.

Faculty Improvement Programs

Participation in the following four 1979 programs was open to all individuals teaching science, mathematics, or social science in U.S. schools, including some one million elementary teachers, 300,000 secondary school teachers of science, and 200,000 2- and 4-year college and university science instructors.

Pre-College Teacher Development in Science

In its third year of operation, this program continues to stress the improvement of the teacher's knowledge of the subject matter of science and to improve communication and cooperation between elementary or secondary school teachers and college or university scientists. Projects are designed either for summer or for academic-year activities. Of the 13,000 participants in the 1979 program, 18 percent were teachers from elementary school, 50 percent from middle and junior high school, and 32 percent from senior high.

In one academic-year project at San Francisco State University 70 middle and high school teachers used earthquake awareness to develop insights into fundamental principles of science and as a theme around which to teach science. The seminar drew on the expertise of research scientists in the Bay area.

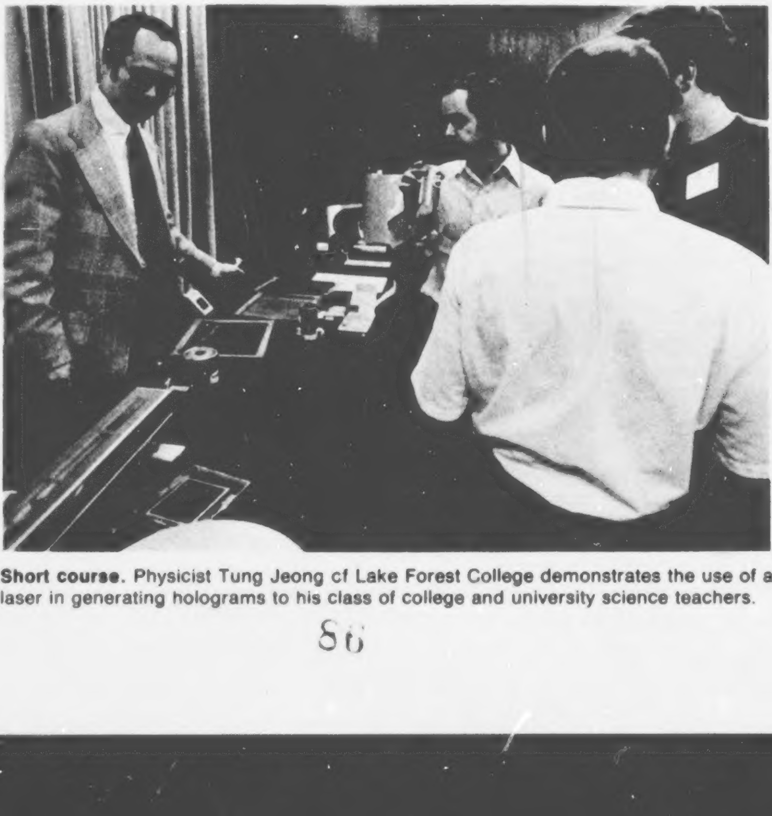
In another project the University of Arizona conducted a four-credit, four-week summer course, "Mineral Resource Technology and the Environment," for middle and high school physical science teachers. The course demonstrated the role of the physcial sciences in mineral resource technology and in the mineral resource engineering disciplines and provided a comprehensive overview of the social, environmental, and economic impacts on Arizona of mineral resource development.

College Faculty Short Courses

This program introduces science faculty to the latest scientific developments so as to expedite their inclusion in undergraduate curricula. The courses consist of two intensive 2-day sessions and an intervening period of several weeks for individual work on a project related to the course. The 1979 program supported the participation of about 3,200 college teachers in 54 different short courses. For example, Roger C. Camp of Iowa State University taught a short course on the introduction of microcomputers into the undergraduate science curriculum. In the fall session he explored the impact of these devices and systems on classroom science instruction and research, while the spring session covered additional topics and a critique of the interim projects. Classroom microcomputers, available for hands-on use, were the basis for interim projects.

Science Faculty Professional Development

In this program awards were offered to 2- and 4-year college and university science teachers for research or study for 3 to 12 months at universities or in industrial or other nonacademic laboratories. This permits teachers of undergraduate students to obtain new insights and perspectives into subject matter which can be transmitted to the students. One teacher, Shannon O'Dunn of Grossmont Community College, in El Cajon, California, studied the natural and artificial changes in the past 100



Short course. Physicist Tung Jeong of Lake Forest College demonstrates the use of a laser in generating holograms to his class of college and university science teachers.

years in the coastal zones, including surf zones, beaches, beach cliffs, and selected adjacent terraces of southern California, northern Baja California, and Mexico. He plans to develop teaching aids on this subject for lower division college students and interested laymen.

Industrial Research Participation

These 10-week summer projects provide research opportunities for college science faculty. Grants are made to industrial and other nonacademic laboratories, who in turn select the participants. This program improves undergraduate science teaching through the direct involvement of college teachers in ongoing industrial research. The projects broaden the backgrounds of the faculty members and help them incorporate an industrial perspective in the course material. Their undergraduate students will be better prepared for, and more likely to consider, future employment in industry.

For example, four academic physicists and electrical engineers worked at General Telephone and Electronics Corporation's Waltham, Massachusetts, laboratories on the use of industrial robots for the handling and assembly of materials, on two-way transmission over a single optical fiber, and on digital technology in speech analysis and synthesis.

Minorities, Women, and the Physically Handicapped in Science

These programs develop and test ways to attract, encourage, and motivate groups underrepresented in science through workshops, career facilitation projects, development of career information, modifications of existing science courses, and special training opportunities beyond those available in existing formal science education programs.

Minorities in Science

In addition to special projects, this program has used the proven models of NSF's student science training, undergraduate research participation, and student-originated studies programs. For example, ten minority students at Hampton Institute, who are studying health and social services furnished to older adults, will supply data to the National Council on Aging and local area agencies concerned with aging. In another project, six minority students at Alcorn State University, Mississippi, will participate in a research program on agriculture pesticides and aerosol propellants.

Elsewhere, Rockwell International Corporation Science Center developed a plan for a comprehensive program to increase the number of Hispanics and native Americans entering scientific and engineering careers. Based on a model to be implemented in New Mexico, the plan entails collaborative efforts of the Federal Government, the State government (both executive and legislative branches), industries, universities, and other educational units, as well as professional and minority organizations.

Women in Science

This program's three components are the visiting women scientist program, the science career facilitation projects, and science career workshops.

Following a visiting women scientist program at the Research Triangle Institute (RTI) in North Carolina, and to assist others in conducting similar programs, RTI prepared a manual on program operations and a roster of approximately 1,300 women scientists who are interested in participating in activities to encourage females to consider science careers.

Under a science career facilitation project in engineering at California State University, Northridge, 52 women holding baccalaureate degrees are participating in a 12-month program of mathematics, computer programming, engineering, and internship experience. The women will be given placement assistance for permanent jobs or for graduate school.

Twenty-eight colleges and universities in 22 States and Puerto Rico conducted science career workshops to provide information on science careers to some 6,600 women undergraduates and postbaccalaureates. As an outgrowth of earlier career conference grants, Emory University and Gustavus Adolphus College, for example, will appoint women scientists to newly created positions as curriculum and career advisors to their women students, to permit them to make better informed career decisions.

Physically Handicapped in Science

This program supported 16 projects in (1) student science training; (2) development of career information; and (3) field testing and evaluation of science courses adapted for the physically handicapped. For example, under one of those awards the American Chemical Society (ACS) is reviewing introductory college chemistry courses to assess the need for modifications in lectures and laboratory activities and equipment for handicapped students. The ACS will produce and distribute a manual to aid college personnel in teaching general chemistry to physically handicapped college students.

Student-Oriented Programs

Student-oriented programs provide opportunities for research and study not usually available to high potential high school and undergraduate students and help them make earlier informed career choices in science and engineering. An important feature is to give the students more responsibility for planning and carrying out their own learning activities.

Student Science Training

This program provides talented senior high school students with coursework in science and mathematics, research participation, or a blend of these through which they come into direct contact with university teachers and research scientists. The projects also expose participants to a wide range of science career choices.

Student Science Training. High school students study the application of remote sensing and mapping to environmental problems during a summer program at Indiana State University in Terre Haute. (Photo by ISU-AVC)

Nearly half of the projects were with high ability students with excellent science backgrounds; the other half were with students of demonstrated high potential but limited science backgrounds. These latter projects focused on students from the inner cities, isolated rural areas, and educationally disadvantaged populations. For example, in one project Detroit-area high school students learned about the basic engineering concepts that underlie automotive functions, then studied the efficiency of energy conversion, vehicle safety, and automotive emission control techniques—through experimentation, student projects, and courses introducing the necessary basic concepts.

In another project, Texas Women's University conducted a summer program to acquaint students with chemical research in such areas as water pollution and the photochemistry of smog and photosynthesis. Talented students from high schools having limited science programs were the participants.

Undergraduate Research Participation

This program arranged for 1,160 talented science undergraduates to work with university science faculty or industrial scientists to gain insight into how research is conducted. Thus, they could evaluate career options well in advance of graduate school decisions. The opportunities for undergraduate science majors to work with industrial research scientists have the additional aim of showing the participants the nature of industrial science career possibilities.

For example, each of ten students at the University of Kansas at Lawrence joined a professor in ongoing research. Topics included several aspects of sociology, including rural poverty minorities in the work world, citizens' efforts to influence social policy, social impact of nuclear power plants, aging, and migration of the elderly. Ten students in engineering at the University of Utah carried out research in the fields of solar energy collectors, recovery of oil from shale, geothermal energy, coal processing, or design of high-efficiency engines.

Student-Originated Studies

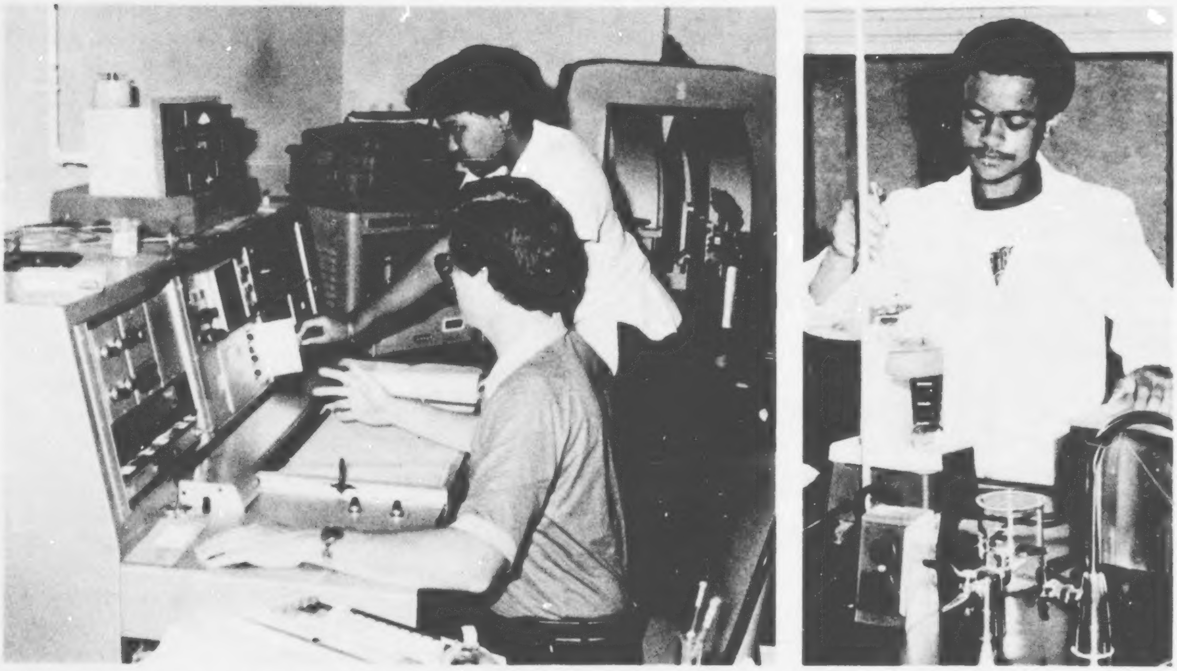
This program encourages students to assume more responsibility for their own learning and to contribute directly to the Nation's research effort on societal problems. More than 530 undergraduate students in 69 interdisciplinary teams designed and carried out projects with minimal faculty supervision. Projects undertaken are generally environmental or societal in nature and provide information of immediate potential use to civic and governmental bodies. For example, at Concordia College in Minnesota ten students completed a feasibility study on community recycling, made recommendations to the city of Moorhead and Clay County officials, and established (as an outgrowth of the studies) a nonprofit corporation to initiate community recycling programs.

Fellowships and Traineeships

These programs support a flow of some of the Nation's most able graduate and postdoctoral students into the advanced science talent pool. The graduate and postdoctoral fellowship programs identify, through national competitions, a limited number of highly talented individuals for awards. The access of underrepresented groups to careers in science is facilitated by awards to individuals through a national fellowship competition and awards to minority institutions, which in turn select the graduate trainees to be supported. Graduate fellowships and traineeships support 3 years of work or study toward an advanced degree in science, while the postdoctoral fellowship supports one year of research for about 100 recent Ph.D. scientists.

Graduate Fellowships

This program accelerates highly qualified beginning graduate students' progress toward becoming members of the Nation's

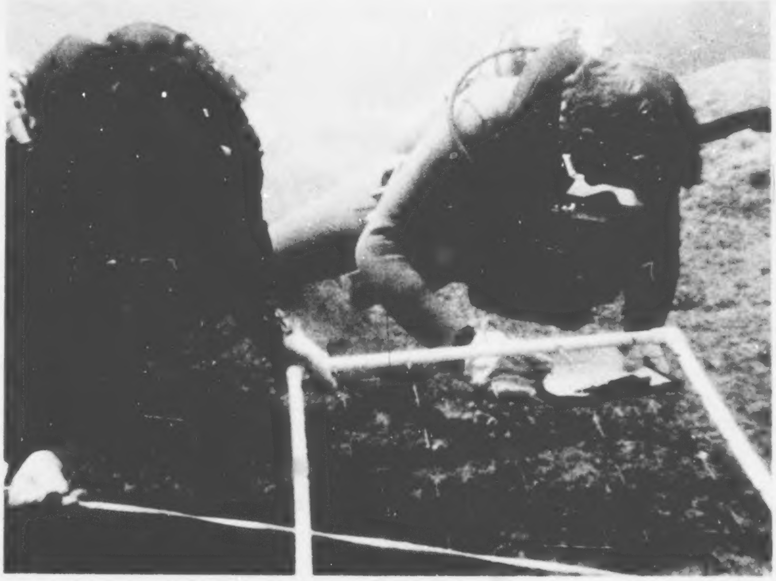


Undergraduate Research Participation. At Jackson State University in Mississippi, two students conduct a nuclear magnetic resonance analysis, and another student purifies dehydrogenase extracted from horse liver.

advanced science personnel pool. In fiscal year 1979, 451 applicants were awarded new fellowships, joining 1,064 continuing Fellows whose course of study is already underway at the institutions of their choice. Another 1,312 applicants were judged highly meritorious and were accorded "Honorable Mention," a designation that enables many of them to acquire other sources of support.

Minority Graduate Fellowships

This program is designed to increase the number of minority practicing scientists in the Nation's scientific community. In 1979 more than 520 individuals who are American Indian, Alaskan Native, Black, Mexican-American, or Puerto Rican competed nationally for 65 fellowships, which were awarded on the basis of merit. In addition, 163 individuals judged deserving of support were accorded "Honorable Mention." The new Fellows will be joining 27 continuing fellows from



Student-Originated Studies. Undergraduates in a project at the University of Hawaii survey marine corals off the Island of Molokai.

the 1978 experimental program who plan to use the second year of their awards in 1979-1980.

Minority Institution Graduate Traineeships

To promote the entry of underrepresented minorities into the advanced U.S. science personnel pool, NSF offered 3-year awards to predominantly minority institutions to support students pursuing graduate science degrees. This past year's awards will support students in 19 departments at 10 eligible institutions. One trainee at California State University, Dominguez Hills, completed her master's degree in sociology this past year. Based on her academic work, she has been hired as a consultant for the desegregation plan for the Los Angeles School District and has been awarded a Regents' Scholarship to pursue her Ph.D. in sociology at the University of California, Irvine.

National Needs Postdoctoral Fellowships

This program represents one effort to bolster the country's ability to cope with scientific problems of national importance by providing one year of fellowship support to promising recent science and engineering Ph.D.'s who are researching specific areas of national need. Among the 144 new Fellows, one, for example, will study and design improved models for predicting the flow of slurries, which may have substantial impact on the efficiency considerations of coal transport by pipeline.

Science and Society

Programs in science and society reflect the concern of NSF and of the scientific community with the complex issues that arise out of the changing relationship between science and technology and the society in which they exist. The activities of these programs are based on the assumption that the health of both science and society requires (1) a widespread understanding of the increasingly complicated base of science and technology underlying matters of personal choice and public policy on which citizens must make decisions; (2) mutually respectful interaction between the ethical and social values and standards of the scientific community and those of society as a whole; and (3) full and informed participation by scientists and other citizens in decision-making processes that involve science and technology.

Table 8
Science and Society
Fiscal Year 1979

(Dollars in Millions)

	Preliminary Proposals		Proposals		Awards	
	Number	Amount	Number	Amount	Number	Amount
Ethics and Values in Science and Technology	200	$15.00	87	$ 6.99	23	$1.26
Public Understanding of Science	231	41.90	79	9.32	30	3.44
Science for Citizens	352	12.50	287	11.24	52	1.59
Total	**783**	**$69.40**	**453**	**$27.55**	**105**	**$6.29**

SOURCE: Fiscal Year 1981 Budget to Congress—Justification of Estimates of Appropriations (Quantitative Program Data Tables).

Ethics and Values in Science and Technology (EVIST)

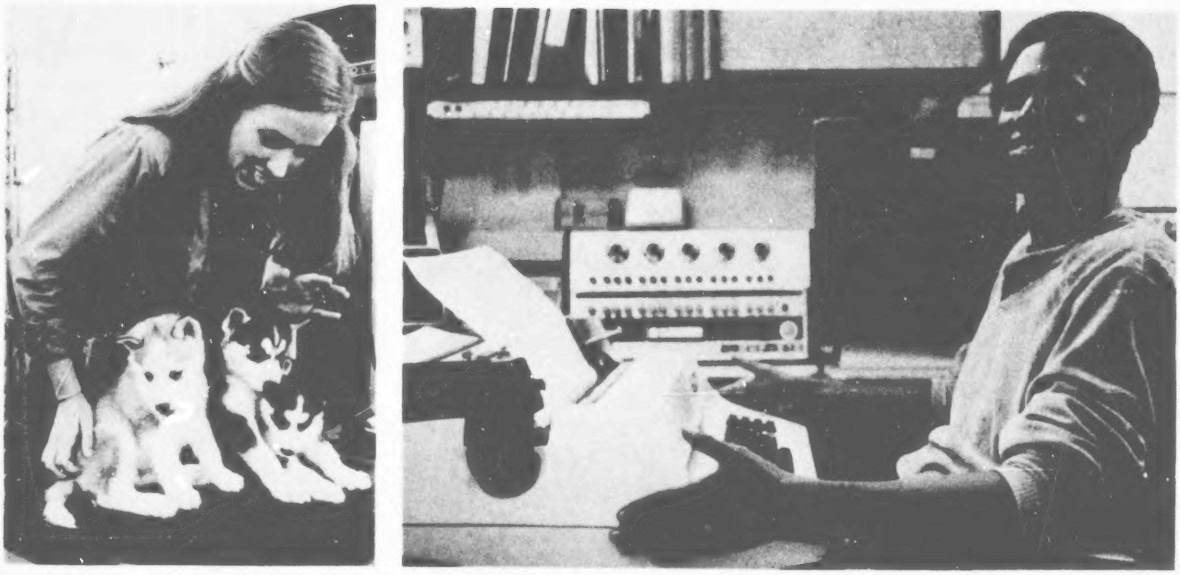
The EVIST program supports projects directed toward identifying, analyzing, and resolving ethical and value issues associated with scientific and technological activities. The following examples indicate the range of topics and activities along these lines that received support during the past year.

An interdisciplinary group at the Franklin Pierce Law Center in Concord, New Hampshire, has been investigating and analyzing the use made by seven Federal regulatory agencies of methods such as cost-benefit and risk-benefit analysis to manage scientific and technological developments. The conclusions reached by the group, including a number of recommended procedural changes to facilitate wider public participation, have been endorsed by the Administrative Conference of the United States.

A book entitled *Ethical Conflicts in Computer Science and Technology* by Donn B. Parker was published commercially in June 1979. This book, which is based on the results of an EVIST-supported interdisciplinary conference, is expected to be particularly useful to teachers and students in college and university courses in the computer sciences, as well as to computer science and engineering societies in helping them to frame professional codes of ethics.

A series of 2-day workshops on ethical issues associated with the production and uses of toxic substances was organized in Washington, D.C., by the Technical Information Project, Inc. These workshops focused on toxic substance issues as they affect industry, labor, government, and the consumer. Presentations at the sessions were solicited through a widely circulated series of announcements and selected by an interdisciplinary committee.

A group at the University of California, San Diego, organized a week-long conference for advanced undergraduate and graduate students on science and ethical responsibility. Participants were selected



3-2-1 Contact. A daily half-hour television program on Public Television to introduce children to science and technology was readied for broadcasting in January 1980. In these two sequences, the young hosts learn about food and growth (left) and computers and speech (right). (Photos by Ken Howard)

nationally, in part on the basis of essays they submitted on specific topics related to the general theme of the conference. Faculty for the conference included several senior scientists who have been active in the United States Pugwash movement.

The American Society of Public Works Administrators scheduled a 1-day intensive workshop on ethics and the public works practitioner in conjunction with its annual national meeting in October 1978. Participants included city and State engineers from throughout the country. Edited proceedings are being published for free distribution to local chapters of the society and to engineering schools.

Public Understanding of Science (PUOS)

This program helps nonscientists understand the activities, methods, and implications of science as well as the issues raised by new discoveries and technology. PUOS supports the use of a variety of media to help the public learn about science-related issues in an informal and recreational milieu.

In the area of broadcasting, for example, the program has provided the primary support to plan and produce "3.2.1 Contact," a new half-hour daily public television program for 8- to 12-year olds. The program reflects almost 2 years of preliminary research to study the interests and understanding of children of this age. Planning, content, and production have been based upon advice and counsel from educators, scientists, and media producers throughout the United States, and the material has been designed both to be entertaining and to introduce a variety of basic science concepts and experiences. The series is available for off-the-air recording by educational institutions and is accompanied by an extensive program of community support and supplementary teaching materials.

"3.2.1 Contact" is particularly addressed to the interests of young girls and minorities, who often tend to avoid science and mathematics. The series is an effort to help children experience the joy of exploration and creativity, to become familiar with the process of scientific reasoning, and to recognize the relevance of science in contemporary society. In all, "3.2.1 Contact" is an effort to make science more inviting to the Nation's children at a crucial time in their lives, when their attitudes toward the subject are likely to take a decisive turn.

Many PUOS projects are directly concerned with the impact of science and technology on local and regional issues and problems. Thus, NSF has helped establish two regional public television series that deal directly with such topics. "Synthesis," a west coast series produced by KPBS-TV in San Diego, continues to produce programs on topics like arctic resource development. The Southern Educational Communications Association is currently developing a comparable science series for its region. The NOVA television series, which was established with NSF support, continues to reach one of the largest public television

Science in the streets. (Above) A group in Puerto Rico gathers to watch a puppet show about health and nutrition. (Below) An audience in a Philadelphia shopping mall watches science demonstrations put on by the Franklin Institute. (Photo by I. George Bilyk)

audiences with science information of national interest.

Museums are another important channel of public contact with science activities and concepts. Science museums attract an audience that is roughly as large as all other kinds of museums combined. NSF provided the initial support for the establishment of the Association of Science and Technology Centers and continues to support activities that circulate science exhibits to museums with a combined annual audience of almost 40 million persons. Many of these museums are experimenting with new techniques to reach the still wider audience that does not attend. The Franklin Institute Museum in Philadelphia, for example, has established a science center in a shopping mall where science programs and exhibits reach teenagers and families who otherwise might have little contact with science.

In order to make the most cost-effective use of limited resources, NSF has encouraged the production of duplicate exhibits and projects which will reach several museums. In one such project, the Hansen Planetarium in Salt Lake City, Utah, recently completed an audiovisual presentation of the life of Albert Einstein. This presentation has proved to be exceptionally popular and copies of the sound-slide program have been presented in over 500 planetariums throughout the United States.

As scientific and technological issues acquire increasing significance, it is important that journalists have a comfortable working familiarity with the world of science and technology. NSF recently supported a science reporting workshop conducted by the journalism department of Lehigh University in Bethlehem, Pennsylvania. The importance of such training was later highlighted by the incidents of Three Mile Island. NSF also supports the annual "New Horizons" briefings of the Council for the Advancement of Science Writing, as well as the mass media fellowships of the American Association for the Advancement of Science.

Several programs are directed toward broadening science interest among groups that otherwise might not recognize its relevance. In Puerto Rico, the Committee of Workers for the Protection of Consumers presents television programs and puppet shows in rural areas to educate children and their parents about health science and nutrition. The University of Colorado has developed an elaborate program of science tours, lectures, and workshops conducted by and for senior citizens. Similarly, the University of Missouri broadcasts a weekly program on public radio stations throughout the State about science for the elderly. The University of Texas has developed a popular astronomy radio program in both English and Spanish. These programs are also included as program material on some transcontinental airline flights.

Science for Citizens (SFC)

Science for Citizens. Delegates from surrounding villages arrive in Wales, Alaska, for a demonstration workshop on water and waste problems.

This program supports activities that encourage scientists and engineers to participate in public activities aimed at the resolution of local or regional policy issues with significant scientific and technological aspects and that provide scientific and technical expertise to citizens and citizen groups so that they can better understand and participate in decisions on issues of this kind.

In its third year, the public service residencies program made 26 awards. These residencies enable scientists and engineers to undertake up to a year's activities with citizen groups and other organizations in need of their expertise. This year, for example, a chemist is working with the New York State Department of Environmental Conservation evaluating health risks from the consumption of chemically contaminated fish and is developing informational materials for public dissemination. A sociologist is working with La Union Hispanica of Suffolk County, New York, where she will train community leaders in data collection and analysis to help them deal more effectively with problems of suburbanization.

Previous award recipients have produced a wide variety of materials: energy conservation handbooks; papers on toxic substances in art supplies and on auto emissions and air quality standards; articles for community newspapers and union newsletters on environmental and occupational hazards; and new research on such topics as the economics of urbanization, storm runoff, and drainage proposals. Their work has influenced the organizations and communities with which they have been associated to consider new measures to solve or ameliorate some of their problems.

Also in its third year, the forums, conferences, and workshops program made 14 new awards. With NSF support, scientists and citizens will undertake analysis and public education projects about local or regional policy issues that involve science and technology. For example, with the help of a broad-based advisory committee and several project scientists, Save the Bay, Inc., of Rhode Island will sponsor a series of follow-up meetings to consider how Providence might best make necessary improvements to its sewage system, develop pretreatment regulations without disrupting the economically important jewelry industry, and expand Providence's port area.

In addition to research papers and background materials, previous award recipients have produced a variety of handbooks and other publications intended to help citizens and their organizations to develop programs on issues of local and regional concern. Preliminary results from these projects indicate that scientists can generate presentations, materials, and papers which lay citizens find useful. Citizens, in turn, believe themselves to be better informed about particular issues in their community and better able to participate in decision-making about those issues. SFC projects have resulted in new policy initiatives on topics such as road de-icing practices, community water management, regulation and enforcement of surface mine blasting procedures, encouragement of alternative energy development, substitution of generic for brand-name drugs, and notification and retraining practices for industry or mine closings.

In its second year, the planning studies program made seven new awards to enable scientists and citizens to devise public service science centers where ongoing programs can be responsive to community needs for scientific information and advice on policy issues. For instance, the Dallas Public Library is assessing information needs and resources for the city, testing several models for information exchange, and sponsoring a city-wide conference to discuss project results and plan a permanent information exchange. Many recipients of planning study awards have also produced registers and handbooks designed to inform citizens about scientific resources in their region and help them organize public service science activities.

9

Engineering and Applied Science

5

The Engineering and Applied Science (EAS) programs seek to strengthen the U.S. research base and enhance the links between research and its applications in meeting selected national goals. This is accomplished by supporting basic research in the engineering sciences and applied research and related activities with high potential for contributing to the understanding and resolution of significant societal problems.

The specific objectives of EAS are to:

- Advance knowledge of fundamental engineering principles that might be applied to the analysis and design of manmade systems and their subsequent applications to societal needs.
- Stimulate the application of fundamental scientific and engineering knowledge to significant problems in the public and private sectors, and shorten the time between scientific discoveries and their application for societal use.
- Focus U.S. scientific and technological capabilities on selected problems of national significance where NSF can make a unique contribution.
- Increase fundamental scientific knowledge in problem areas where additional knowledge can contribute to their long-term solution.
- Provide mechanisms to increase the effectiveness of the public and private sectors in using science and technology.
- Explore new ways to improve cooperation between universities and industry in research and industrial innovation.
- Stimulate research in selected States and increase the ability of scientists in those States to compete successfully for Federal research funds.
- Facilitate the integration of scientific and technical resources into the activities of State and local governments.

To implement these goals, EAS focuses on six areas.

Electrical, computer, and systems engineering—basic research in the three related disciplines of electrical, computer, and systems engineering. Programs cover broad areas of advanced automation; bioengineering; computer engineering; communications and information processing; microstructures; systems theory; and operations research. The program supports the National Research and Resource Facility for Submicron Structures at Cornell University, which is available to researchers throughout the Nation. The program is currently giving special emphasis to research on microstructures, robotics and cognitive systems, and investigations in large-scale systems.

Chemical and process engineering—basic engineering research relevant to the entire range of chemical, petrochemical, biochemical, food, mineral, and other process industries. Examples of areas supported include kinetics of catalytic and biochemical processes, reactor dy-

Table 9
Engineering and Applied Science*
Fiscal Year 1979

(Dollars in Millions)

	Number of Awards	Amount
Electrical, Computer, and Systems Engineering	340	$ 17.04
Chemical and Process Engineering	277	12.97
Civil and Environmental Engineering	132	8.15
Mechanical Sciences and Engineering	194	10.76
Industry/University Cooperative Research	31	3.78
Intergovernmental Science and Public Technology	156	8.05
Applied Research	153	19.90
Problem-Focused Research	432	33.94
Total	**1,684**	**$114.59**

* The Directorate for Engineering and Applied Science was formed during fiscal year 1979 by merging NSF engineering programs with those in applied science and research applications. Consequently, program expenditures reported for prior years are not comparable with those being reported here for fiscal year 1979.

SOURCE: Fiscal Year 1981 Budget to Congress—Justification of Estimates of Appropriations (Quantitative Program Data Tables) namics and process control, plasma chemistry, combustion, thermodynamic and transport properties, separation techniques, interfacial phenomena, and fine-particle characterization and processing. Specific program emphases are chemical processes, engineering energetics, thermodynamics and mass transfer, and particulate and multiphase processes.

Civil and mechanical engineering—a broad array of research ranging over mechanical and thermal phenomena important in engineering applications. Specific research areas are geotechnical engineering, structural mechanics, water resources and environmental engineering, solid mechanics, fluid mechanics, heat transfer, and mechanical systems.

Applied research—projects initiated by the scientific research community to improve understanding of various social, economic, policy, and technical problems and to increase the rate of innovation stemming from discoveries in science and engineering.

Intergovernmental science and public technology—integration of science and technology resources into the activities of State and local governments, and test and evaluation of incentives that the Federal Government may use to increase private R&D investment and to stimulate innovative technology in important areas of the private sector.

Problem-focused research—research to clarify and/or resolve critical societal problems by the application of science and technology. Emphasis is on earthquake hazards mitigation, alternative biological sources of materials, science and technology to aid the physically handicapped, and human nutrition.

Electrical, Computer, and Systems Engineering

The rapid, almost explosive, growth of the semiconductor integrated circuit industry continues to fuel revolutionary growth in automation, communications, and information processing. In turn, the needs of the "intelligent electronics" technology drives activities in submicron structures research and computer engineering research.

In submicron structures research, the cornerstone of the program is the National Research and Resource Facility for Submicron Structures located at Cornell University and available to all qualified researchers. The facility is to be both a fabrication resource for the academic and general research community and a research center for fabrication-related technologies. Several significant research results have already been recorded by the facility. These have been in the generation of intense ion beams, thin-film growth by molecular beam epitaxy, silicon-on-sapphire field-effect transistor fabrication, and integration of optical components in integrated optical circuits. Basic studies of the electronic conduction and resonance properties of very small (50-angstrom-diameter) metal particles have also been carried out.

The facility is nearing full strength as major pieces of fabrication and diagnostic equipment are installed. The metal particle measurements were made using a scanning transmission electron microscope recently brought into operation. Thin-film studies are now using a molecular beam epitaxial film growth reactor and the largest piece of equipment, an electron beam pattern generator, is undergoing final testing.

In addition to the Cornell facility, NSF's submicron program supports other microfabrication and small-device research. A notable recent accomplishment is a modeling program to characterize X-ray and other techniques for the generation and replication of device patterns. The model has been used to predict successfully pattern replication distortions that arise as a result of the presence of standing waves in near ultraviolet optical systems. Research programs in electron-beam lithographic techniques, in plasma etching, and in modeling of small-device structures have also been initiated. Research in magnetic-bubble memory systems and in surface-acoustic-wave signal processing devices also emphasize significant submicron and microfabrication aspects.

In communications research, the need is for theoretical knowledge of what topology, protocol, and dynamic architectural reconfiguration optics are available and desirable for computer communication networks and in multiuser broadcast channel systems. Good fundamental investigations are in progress in this area.

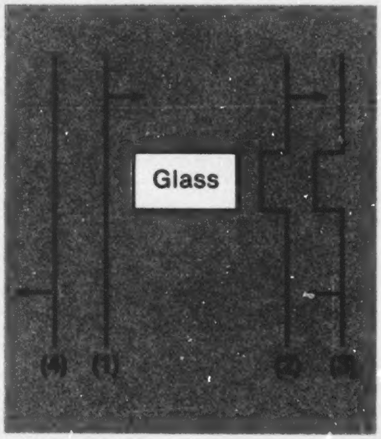
In systems theory and operational sciences, work is supported in optimization and mathematical programming, in decision theory for stochastic systems, in modeling and analysis of service systems (such as production systems and network and commodity flow problems), and in the study of large-scale (complex) systems. Specific accomplishments include improved Kalman filtering approaches to the interpretation of geological prospecting data and formalization of the so-called reduced-order modeling of large-scale interconnected systems. In the latter topic, a new concept, mutual modeling, is being introduced. This concept recognizes that in many large-scale system situations, different controllers (i.e., decisionmakers) have different information about the system and, hence, will be using different simplified models of the same system. They may also have different performance goals. The mutual modeling approach is perceived as an iterative process in which the modeler of one subsystem communicates his simplified model to all other modelers. The others, in turn, update and improve their own models of the system. A major research goal is to develop an analytical framework for studying the properties of this iterative modeling process.

In the quantum electronics area, work in the plasma area concentrates on basic studies of control and manipulation and, occasionally, fallout from this type of research has impact on the fusion energy programs. A typical recent result is the discovery of a mechanism for electromagnetic emission from plasmas at a frequency which is the geometric mean of the ion plasma oscillation frequency and the electron plasma frequency. In the field of lasers and optics, free electron lasers, picosecond laser techniques, and conjugate wave generation constitute the most exciting areas of progress.

In automation, research is growing in all aspects of machine decision and control. This increased interest has been stimulated by a new generation of microcomputers, improved electronic and electro-mechanical components, as well as advances being made in the cognitive sciences. To capitalize on the strides that have taken place, NSF is emphasizing research in machine decision and control. Researchers are currently trying to understand how machines can perform such functions as logical inference, self-learning, vision and perception, and end effector control. Ultimately the research will include other elements needed to create a machine that can function in a non-predictable environment by using imprecise information while adapting to a changing problem domain.

Optical Phase Conjugation

The propagation of optical waves through a nonuniform medium typically results in undesirable distortion of the optical wavefronts. There are many situations in which it would be desirable to minimize these effects. Consequently, techniques for reducing distortion in nonuniform media are in high demand. In independent investigations, Robert W. Hellwarth of the University of Southern California (whose research on a nonlinear optical microscope was reported in last year's *Annual Report*) and Amnon Yariv of the California Institute of Technology are currently studying a promising approach to this problem that uses phase conjugate or "time-reversed" waves generated by nonlinear optical interactions.



Example of phase conjugation. An undistorted optical wave (1) moving to the right encounters some local change in the transmission medium and emerges (2) with a distorted wave front. A conjugate wave (3) would be the same shape as (2), but moving in the opposite direction. If (3) is propagated back through the medium, it emerges (4) undistorted, identical to the original wave.

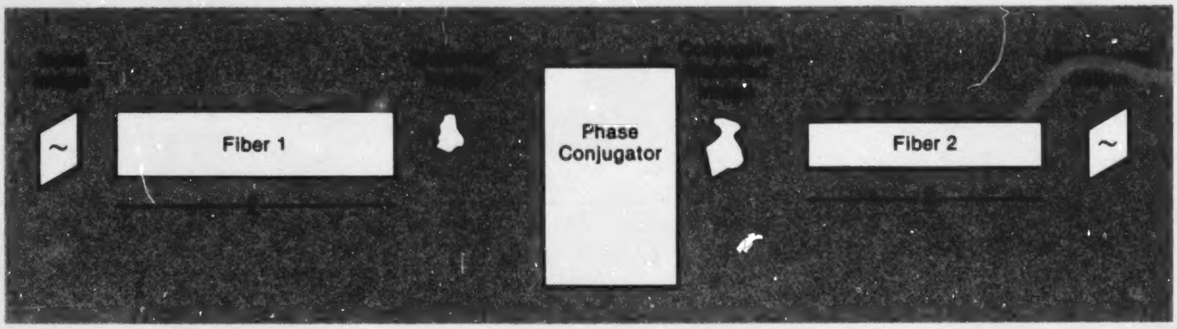
The phase conjugate wave "undoes" the undesirable effects of a distorting medium in the following way. Consider an undistorted plane wave with a flat wavefront traveling through a medium which, due to the presence of a glass cylinder, has a nonuniform index of refraction. After passing through the nonuniform region the wave has a distorted wavefront because of spatial variation in its propagation velocity. The phase conjugate for this distorted wave would be one with an identical wavefront but traveling in the reverse direction. If a "phase conjugator" could be constructed to generate this wave, it could be propagated back through the distorting medium and would emerge as an undistorted wave with a uniform wavefront. Thus the original wave would have traveled twice through a distorting medium and emerged undistorted.

The primary obstacle to this distortionless propagation is to generate the conjugate or time-reversed wave. It is here that Hellwarth and Yariv have made substantial contributions by demonstrating that the conjugate wave can be generated using nonlinear optical techniques.

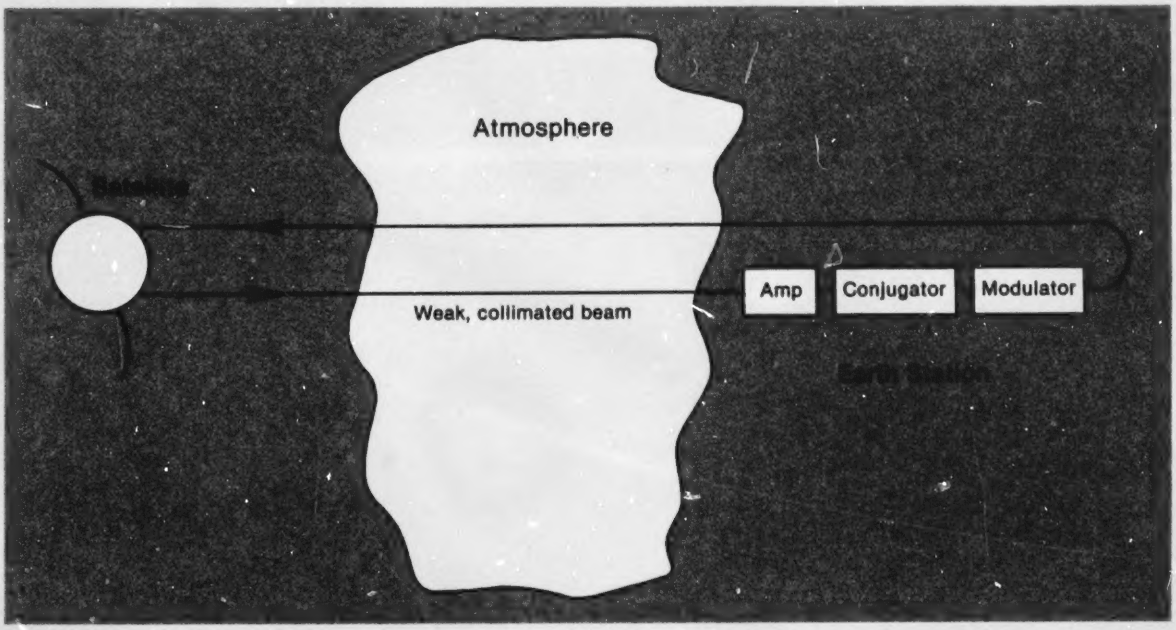
Although several nonlinear optical effects are useful for conjugate wave generation, perhaps the most successful is the "four-wave mixing." In this arrangement strong pump beams from two intense laser sources are propagated in opposite directions through a nonlinear medium. A medium of this type allows the two pump beams and a weaker input beam to interact and generate a fourth beam which travels in a direction opposite to that of the input. This fourth beam can be shown to be proportional to the conjugate of the input beam, and its conjugate nature has been verified in experiments with a number of nonlinear optical materials. This simple device thus acts as an "optical phase conjugator," and a variety of applications have been proposed.

Good examples of such practical applications can be found in the area of optical communications. Images transmitted through fiber optic wave guides suffer distortion because waves in these guides travel in several different propagation modes, each of which has a different propagation velocity. This type of distortion, inherent to large-diameter optical fibers, can be corrected by an optical phase conjugator. If the fiber is divided into two equal lengths by an optical conjugator, the waves travel once through two identical media. Distortion introduced in the first segment is "undone" in the second segment after phase conjugation, and the image emerges undistorted.

Another important application is related to satellite communications. Laser optical communication links between satellites and earth stations offer potentially high information capacity. Atmospheric distortion, however, produces a slowly time-varying spatial modulation of a transmitted laser beam and spreads out the beam as it propagates. These problems can be alleviated by using a similar approach. A weak, collimated beam is transmitted from the satellite to Earth and in the



Optical fiber corrections. Theoretically, a phase conjugator, placed midway between two equal lengths of optical fiber, could correct for distortions introduced by the wave propagation process.



Satellite communication possibility. An initial optical signal being sent to Earth is distorted by the atmosphere. The earth station would then amplify and conjugate the signal, add the information for transmission to it, and send it back through the atmosphere. It would emerge undistorted at the satellite.

process is distorted by the atmosphere. At the earth station the beam is amplified, conjugated, and then has the information to be transmitted impressed upon it. After that it is retransmitted to the satellite along the same optical path. It emerges from the upper atmosphere with the same spatial qualities associated with the initial weak beam, and the effects of atmospheric distortion are thereby removed.

Phase conjugation devices have a number of other interesting applications in areas ranging from spectroscopy to inertial confinement fusion. They are a good example of some of the exciting new developments resulting from work in the field of nonlinear optics.

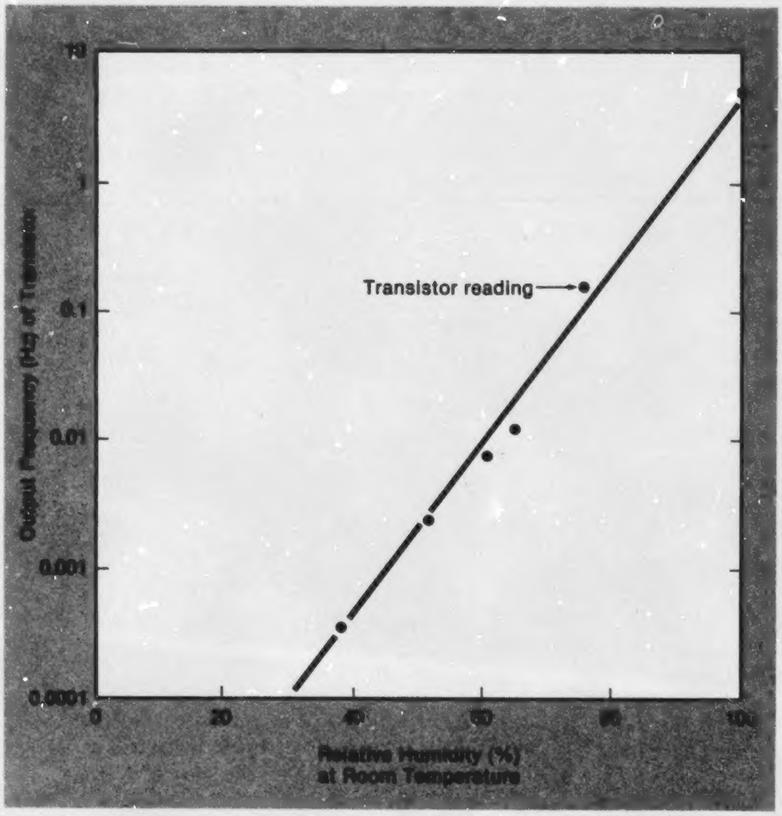
Microelectronic Chemical Sensors

An emerging branch of electronic device research that promises to yield significant future return is the integrated electronic chemical sensor. Research in this area is concerned with incorporating structures sensitive to environmental factors—such as the presence of specific low-density gaseous constituents in the air—into electronic circuits to provide data directly in a form suitable for further processing. In a series of experiments performed at the Massachusetts Institute of Technology, Stephen Senturia and his students have demonstrated a device that detects atmospheric humidity and significantly advances the status of integrated sensor research.

Senturia's sensing device is called a charge flow transistor. The central element is a field effect transistor that contains a gate conductor made from a humidity-sensitive polymer (polyaminophenylacetylene). The field effect transistor is a standard electronic component used in many integrated electronic circuits; ordinarily the transistor control terminal or gate in these integrated circuits is a highly conducting metal electrode. The gate in the charge flow transistor, however, has a conductivity that varies with the ambient humidity.

The combination of the gate conductor with an adjacent gate insulator creates a time-delay element that alters the operation of the transistor in accordance with environmental conditions. The transistor is also part of a larger structure which produces a signal that oscillates at a frequency determined by the state of that gate electrode in the charge flow transistor. The oscillation frequency of the device usually can be measured with great precision; thus, the humidity in the environment of the device can be determined.

The significance of this device lies in part in the fabrication technique that has been developed. The structure is made using customary integrated circuit processing techniques but with an additional step to include the polymer gate electrode. The entire device, which consists of four transistors plus additional electric circuit elements, is made on the same chip in a single fabrication procedure. With this as a component, it should be possible to incorporate sensing devices in a large-scale integrated circuit that will both process the information obtained and use that data to control the local environment.



Integrated sensor. A tiny, experimental transistor provides an output signal that can be readily converted to a measure of the relative humidity in which the device is operating. Such sensors could be incorporated directly into integrated circuits and provide new ways to monitor and control environmental conditions.

It should also be possible to expand the range of measurements that can be made. Research is already underway on ways to measure the presence of specific gases in the environment and to detect pressure, temperature, and other environmental parameters. Future low-cost integrated sensors may detect and process a host of environmental factors that occur in a wide variety of activities associated with chemical, mechanical, and other processes.

Chemical and Process Engineering

NSF's programs in chemical and process engineering emphasize the development of engineering principles, methodologies, and data base needed to synthesize, optimize, and scale-up industrial processes involving the conversion of material and energy. Special emphases are given to supporting young engineering faculty members and providing sophisticated instrumentation and equipment to improve both the quality and efficiency of the research performed. Cooperative research between industry and universities is also actively encouraged.

With the Nation's attention focused on energy and resource problems, chemical and process engineering is capturing the imagination of many young researchers and attracting a large number of new practitioners. One evidence of this is the mushrooming enrollments in chemical engineering departments in academic institutions across the country. With such growth in participation and interest in research, it appears promising that we will make substantial progress toward converting agricultural wastes into food and fuels, recovering residual oil from existing reservoirs, synthesizing new materials to replace the dwindling supply of minerals, and controlling environmental pollution.

The impact of such impending achievements cannot be overestimated, because the chemical and process industry has traditionally been one of the strongest performers in the U.S. economy. Its activities involve 10,000 firms and directly provide 2 million jobs in the U.S. labor market. The ensuing $150 billion annual sales volume currently contributes a favorable trade balance of over $5 billion per year.

Filtration Research

A glimpse of the NSF impact on the development of the fundamental knowledge base can be obtained from the September 1979 Second World Filtration Congress held in London. U.S. participation accounted for one-third of the papers presented, with a 40/60 split between university and industry. Of the eight papers from U.S. academic institutions, seven were by NSF grantees. This is remarkable considering that filtration became a separately identified NSF program less than 4 years ago. The three contributions reported here each represent a revolutionary approach to filtration research; the quality of the scientific work and the significance of the results to date won high acclaim from the international scholars attending the Congress.

Filtration is important in such wide-ranging industrial applications as wastewater treatment, air-cleaning, extraction of juices from agricultural products, and recycling of lubricating oil. As in many other separation operations, filtration is a crucial step that makes or breaks the entire process.

Despite such importance, filtration remained an empirical art for a long time because of the complexity of the multiphase medium. Even the analytical knowledge gained to date has been based on a number of simplifying assumptions with regard to the compressibility and porosity of the filter cake, the characteristics of the septum (the support for the filter cake), and the pressure drop across the filter cake. The theories thus developed, while adequate in the past, can no longer meet the stringent requirements needed for the design and operation of the new generation of filtration equipment.

Under NSF support Max Willis at the University of Akron is developing a new theoretical framework based on the multiphase equations of change. The presence of a finely dispersed phase—such as tiny particles or liquid or gas droplets in another continuous, immiscible fluid, constitutes a multiphase system. As with other multiphase systems, filtration has been dominated by intuitive models based on experimental observations.

The currently accepted model for the volume of material filtered over a period of time presumes that the filtration rate decreases because of the added resistance to fluid motion as solids build up on the filter cake on the septum. The integration procedure used to develop this model assumes an idealized, incompressible filter cake. The real behavior of the filter cake was accounted for by correction factors or, in some cases, described only empirically. As a result, the influence of the septum resistance remained unresolved, even though the basic model has existed in various forms for nearly 70 years.

Willis' research, conducted over the past 3 years, consisted of an experimental program running concurrently with a theoretical analysis. The traditional model (known as the "parabolic" model) was taken as the starting point for the experimental program, which had a specific objective to establish the operating conditions that would give parabolic behavior. The results were contradictory in spite of elaborate experimental precautions. The most vexing problem was the observation that a given cake under supposedly identical filtration conditions could exhibit both parabolic and nonparabolic behavior. The resolution of this problem came only after the full significance of the theoretical results became apparent.

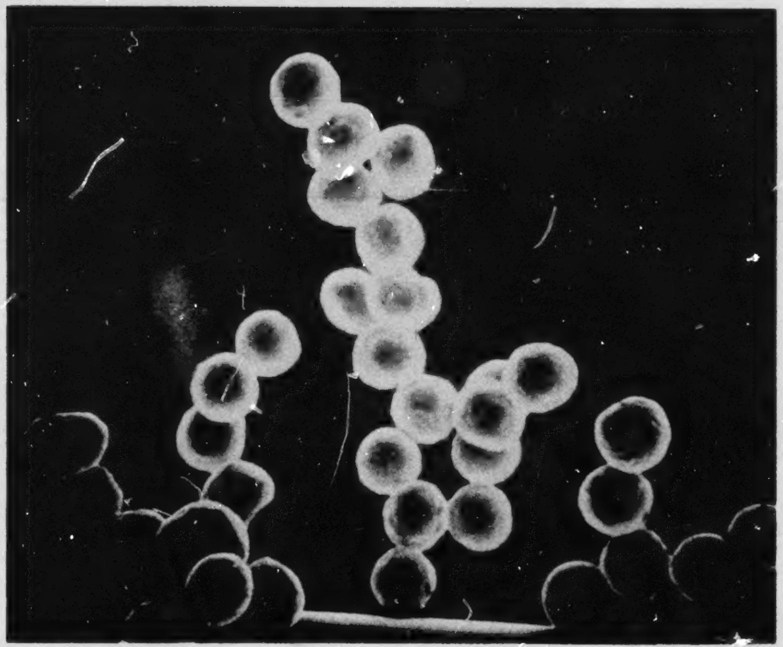
The parallel theoretical development was based on the multiphase equations of change. A significant feature of this theory was the requirement that the local fluid velocity be evaluated at the cake exit and not be integrated over the filter cake. This meant that the filtrate rate was determined by the permeability of the septum and that this permeability was affected by the interaction of the septum, the cake solids, and the fluid.

Reevaluation of the previous experiments revealed that the influence of the septum was the reason for the apparent contradiction of a given cake exhibiting both parabolic and nonparabolic behavior. This reevaluation showed that a nonclogging septum exhibited a nearly constant septum permeability, a linear pressure distribution, and parabolic behavior; a clogging septum exhibited a decreasing septum permeability, a nonlinear pressure distribution, and nonparabolic behavior. In addition, Willis found that this theoretically based filtration equation is generally applicable to all filter cakes and overall filtration times and is not subject to the restriction imposed on the parabolic model of filtration.

The new theory alters significantly the basis for filtration equipment design. Based on the correlative model, designers would alter cake properties to obtain parabolic behavior, since it represented the ideal or "best" filtration. However, this new characterization implies that in filtrations with a small cake buildup it is better to strive for nonparabolic behavior using a clogging type septum with high initial permeability because, in this case, a larger amount of filtrate will be collected than that collected using a nonclogging septum under the same conditions. On the other hand, filtrations with a large cake buildup should use a nonclogging medium and strive for parabolic behavior.

In a parallel attack on the idealized model, Frank M. Tiller at the University of Houston (and winner of the 1978 Gold Medal of the Filtration Society) has been revising the constant-pressure filtration theory. Constant-pressure operation has dominated both theory and experimental procedures in filtration for many years. The general objective of constant-pressure filtration experimentation is to determine the resistances of filter cakes and supporting media. Numerical techniques for obtaining these resistances have been based on the previously described parabolic theory. For more than half a century, advance of constant-pressure filtration theory has been frustrated by the domination of the field by that theory. Although the basic information necessary for modification of existing theory appeared in the literature around 1930, and 20 years later it was shown that the parabolic relationship was only an approximation, it was not until 1979 that Tiller and co-workers J.R. Crump and Francoiss Ville revised the commonly accepted theory.

While investigating filtration of liquified coal, they discovered that the filtration parabola did not apply to early stages of experiments. As a consequence, errors have been made in calculating both medium and cake resistances in the past. As a general rule, short filtrations with a high-resistance medium lead to an accurate determination of the medium resistance but to inaccuracies in the cake resistance when classical methods are applied. Conversely, long filtrations yield accurate values of cake resistance, but then the medium resistance is inaccurately given.



Filter deposition. Under some conditions, particles being filtered through fibers (such as the one at the bottom of the picture) will deposit in such a way as to increase the filter's efficiency by trapping more particles themselves. Knowledge of the effects of different fiber geometries is important for improved filters for pollution control.

The third piece of filtration research is that of A.C. Payatakes, Tiller's colleague at the University of Houston. While the investigations by Tiller's group deal with solid-liquid separation, Payatakes has been developing a fundamental model of gas filtration. Improved pollution control makes the removal of particles, especially those in the submicron range, from gaseous emissions (for instance, coal-fired boilers, cement kilns, asphalt plants, etc.) imperative. Several industrial processes involve one or more stages where fine particles must be removed from gaseous streams (such as removal of particles and viruses from air supply in aseptic fermentation, removal of particulate mineral material and char from the product of coal gasifiers, etc.). Hence, there exist great incentives to improve the present gas-solid separation methods and/or develop new ones with better performance characteristics in terms of efficiency, energy consumption, compactness, and temperature tolerance.

Filtration through fibrous filters has a number of important advantages. It is highly efficient, requires relatively low energy consumption, and lends itself to the design of compact systems. But better design of fibrous filter systems requires quantitative understanding of the deposition phenomenon. The pattern in which particles are deposited on the fibers is very complicated and has profound consequences on the filtration efficiency and the concomitant energy consumption.

As it turns out, depositing particles form chain-like agglomerates on the filter fibers. Similar phenomena are observed with collectors other than fibers, as long as the characteristic dimension of the collector does not exceed that of the particles by more than one or two orders of magnitude. These agglomerates are themselves efficient collectors, increasing both the filter efficiency and the required pressure drop.

Payatakes' group first developed theoretical models of this process for aerosol particles with diameters of one micrometer or larger. The model was then extended to the case of submicron particles. Fine fibers are considered as collectors, but the model can be easily converted to other geometries, such as particles. The various models cover all cases involving submicron particles and fibers with radii greater than one micron.

Payatakes' theory, which predicts the rate of growth of agglomerates as well as the effects of filtration efficiency and energy consumption, is valid during the first and second stages of filtration—almost up to the point where the agglomerates start intermeshing with their neighbors. One of the most important features of deposition by submicron particles is that the agglomerates grow on the entire surface of the fiber. In the case of deposition by larger particles, they grow only on part of the fiber. For this work, Payatakes became the first American researcher to win the Suttle Award of the Filtration Society.

Plasma Chemistry of Polymers

Chemical synthesis under plasma conditions permits the formation of substances that are impractical to produce under other conditions. Plasma techniques are proving to be particularly effective in the formation of polymers suitable for a variety of potential applications—reverse osmosis, gas separation, biological membranes, barrier coatings, anti-reflection optical coatings, and adhesive bonding of otherwise incompatible materials. Among the advantages of plasma polymerization are the ability to produce a very thin layer of polymer on a surface (so that a material's surface can be modified without affecting its bulk properties) and to graft a surface layer on a wider variety of polymer substrates than is ordinarily possible.

Under NSF support Raymond F. Baddour and Robert E. Cohn of the Massachusetts Institute of Technology have successfully grafted fluorine and amine groups on the surface of low-density commercial polyethylene. In a typical experiment, the reaction chamber is evacuated, after which dilute (5 percent) fluorine or ammonia (mixed with 95 percent helium, which is chemically inert) is introduced into the system. When the pressure in the chamber stabilizes at the desired level, the plasma is ignited and maintained for a specific treatment time with a high frequency generator, after which the system is quickly flushed with helium.

The surface of the treated polymers is then analyzed using several complementary techniques to obtain an overall chemical analysis and to identify various fluorinated species. Research is in progress to elucidate the reaction mechanisms so as to understand more fully the process taking place.

Civil and Mechanical Engineering

Civil engineering, by far the oldest branch of engineering, seeks to improve our physical environment by harnessing the forces and materials of nature. From the pyramids of Egypt to the Golden Gate Bridge, from the harbor of Syracuse to Chicago's sanitary plant system, civil engineers have built tunnels and bridges, highways and waterways, dams and airports. A civil engineer laid out the city of Washington, D.C.

Mechanical engineering, of much more recent origin, grew out of the Industrial Revolution, which was based originally on the availability of power from the steam engine. Mechanical engineers design energy conversion systems, develop manufacturing facilities and processes, and are involved in the design of heavy equipment.

In spite of their well-established traditions, both engineering disciplines remain in the forefront of contemporary research as they are called upon to develop new materials, processes, and design techniques. These, in turn, require a constant flow of new knowledge which can be supplied only by a flourishing basic research activity.

NSF's programs in civil and mechanical engineering have recently been reorganized expressly for the purpose of focusing attention on this type of basic research. Fundamental to both branches of engineering is an understanding of solid and fluid mechanics, each of which is represented by a separate program. Basic to all energy considerations is the heat transfer program. The behavior of structures, both above and below ground, is studied in the structural mechanics and geotechnical engineering programs, while fundamental questions relating to the physical environment are covered in the water resources and environmental engineering program.

As an example of a basic (i.e., broad-based) research program, consider the case of a building subjected to "dynamic loading" such as may occur in connection with wind storms, waves, earthquakes, or the impact of a moving vehicle. The building may contain essential equipment (e.g., life-supporting equipment in hospitals, transformers or circuit breakers in power plants, etc.), and the question that arises is whether such equipment will survive under dynamic load conditions. Research carried out with NSF support by J. L. Sackman at the University of California, Berkeley, has shown that the design methods currently employed are inadequate. In fact, his research has demonstrated that the method of analysis conventionally used (i.e., the floor spectrum method) has serious shortcomings; it is expensive, involves uncertain input, and neglects the interaction of equipment and structure.

Sackman's new analysis and design method accounts for the interaction of equipment and structure, clarifies the question of appropriate input, and bypasses the need for massive, expensive numerical computations. He has also shown that in certain respects the licensing requirements of regulatory agencies are overly conservative and therefore unjustifiably costly. The results of this research project may eventually produce substantial economies in construction.

High-speed X-ray cinematography—or cineradiography, as it is sometimes called—is another recent development. So is its application to research in biomechanics. These developments came about because of the desire and need of researchers in impact trauma studies to observe directly the mechanisms that contribute to injury. With support from NSF and the Motor Vehicle Manufacturers' Association, the Highway Safety Research Institute (HSRI) of the University of Michigan has been developing and applying such a system to various biomechanical research programs. This effort combines a long-existing X-ray technology with modern developments in electro-optics and high-speed photography and has resulted in a system that produces motion pictures of X-ray images at 1,000 frames per second.

One of HSRI's areas of research concerns the improvement of safety helmets to protect workers from falling objects. The experiments involve direct observation of impacts, using the X-ray cinematography combined with an analysis of force and acceleration data. As a result of this work, and subsequent work concerning tolerance of the skull and cervical spine to dynamic loading, HSRI is working toward improved specifications for performance of protective helmets.

The HSRI X-ray cinematographic system can also be adapted to the dynamic evaluation of other types of problems. Part of the versatility of the system is that its image intensifier can be coupled with various input radiation sources and photographic recording devices. It can also be adapted to neutron radiography or gamma-ray radiography, provided suitable sources for these radiations are used. Given a suitable source of neutrons, it should be possible to observe the motion of fuels and lubricants inside steel casings. Several important improvements are now being made in the system, and new equipment will produce three-dimensional quantitative data from biomechanical experiments for use in validating mathematical models. Other changes will enhance the usefulness of the system for investigating problems related to human safety.

Important recent work in the area of fluid dynamics has concentrated on the problem of bluff body aerodynamics—flows past bodies with "flat noses," such as road vehicles, buildings, and certain ship hulls. In the case of the road vehicle, such aerodynamic forces control the drag as well as the side-forces and moments. Thus, both energy efficiency as well as safety and directional stability are involved.

In recent experiments on flow past bluff bodies with a cavity (similar to a tractor-trailer configuration), Anatol Roshko at the California Institute of Technology has demonstrated that the drag penalty due to the cavity can be eliminated. The possibility that properly designed large cavities or breaks in contour can be incorporated into body design without drag penalty is most intriguing. Knowledge of how to do this effectively can benefit the performance of all types of vehicles—land, air, or sea—moving through a fluid.

In water resources, simulation and mathematical models are often used in analyzing ground-water systems. These models are usually nonlinear and difficult to solve, requiring the use of large, high-speed computers. Optimum development and management of a ground-water basin requires an efficient model that describes the response of the basin with given input and management decisions. Furthermore, the model is not valid if factors characterizing the model are not properly identified. Traditionally, a trial-and-error method is used to determine those factors. In the case of a two-dimensional inhomogeneous aquifer, the number of factors is large and there exist uncertainties regarding the division of the aquifer system into sub-regions so that each would be characterized by its own factors. The classical trial-and-error method is no longer feasible.

Recently Wo Yeh at the University of California, Los Angeles, developed a more efficient solution procedure, as well as an identification algorithm for ground-water modeling. The results of this research are expected to be of value to the overall water resources management (i.e., optimal use of ground and surface waters). Some preliminary results have been very encouraging and have led to a general procedure to analyze a broad class of two-dimensional distributed ground-water systems.

Intergovernmental Science and Public Technology

The intergovernmental science and public technology programs:

- Combine the scientific and technological resources of universities and industry in innovative programs to accelerate the introduction of new technologies in U.S. business.
- Integrate scientific and technical resources into the policy formulation, administrative management, and programmatic activities of State and local governments.
- Stimulate research in eligible States and increase the ability of scientists in those States to compete successfully for Federal research funds.
- Support research in technologies that are decentralized, require low

capital investment, are amenable to management by their users, are in harmony with the environment, and are conserving of natural resources.

These objectives are supported in three areas: the industrial, intergovernmental, and experimental programs.

Industrial Program

The industrial program sponsors research on experimental incentives to increase the commitment of U.S. industry to research and development. Such commitment is necessary to increase the flow of innovative products and processes. This increased level of innovation is essential to increased productivity and a favorable balance of trade.

This program thus tests experimental institutions and incentives that will increase the investment of U.S. industry in research and development and the utilization of its results. The chief area of experimentation is the coupling of academic resources to industrial needs, with the objectives of:

- Designing and supporting experimental arrangements that will influence the coupling of the longer range and more fundamental perspectives of academic science with the research needs of industry.
- Aggregating similar fundamental research interests from several firms for jointly funded experimental projects from which no single firm could ordinarily capture sufficient benefits to justify its costs.
- Continuing to exploit the high incidence of technological innovation among small- and medium-sized firms.

In this vein, the program encourages investment in basic research by small and large businesses in cooperation with universities and colleges, and couples the fundamental science underlying selected technologies with industrial users. The principal areas of activity have been university/industry cooperative research experiments and technology innovation projects.

Since 1973, the program has funded ten different University/Industry Cooperative Research Centers. Important lessons from some 50 center-operation years have been learned, some of which have been incorporated into the Presidential Initiative on Industrial Innovation. A chief result of these experiments is the observed support of industry for research centers in "generic" science and technology rather than for research centers organized by product groups.

Another important result is the observation that these university/industry centers primarily depend on the leadership of the principal investigator, particularly after the NSF funding has terminated. NSF is now experimenting with team management systems to ensure center continuation after NSF funding as an alternative to the need for endowments or continuing grants.

The areas of generic research selected for university/industry centers have depended largely on proposals from university departments and associated industry funding commitments. Active areas have been in computer science, applied mathematics, reactant polymers, metal fusion, computer-aided design, polymeric coatings, venture analysis, microprocessors, and chemical circuit elements.

The technology innovation projects program will continue to support research in automated assembly systems, modeling of visual systems and integration of these systems into the computer control of the assembly process, and research on high energy impulse welding. The EAS small business innovation program, also managed within the industrial program, has used a small business innovation research solicitation announcement to stimulate a substantial volume of high-quality research proposals.

Intergovernmental Program

The primary objective of this program is to integrate scientific and technical resources into the policy formulation, administrative management, and programmatic activities of State and local governments. This objective is pursued through programs in individual jurisdictions and the establishment and strengthening of statewide, regional, and national networks. Achievement of this objective will enhance the roles of local and State governments in implementing Federal policy and program objectives and in using those scientific and technical resources in which the Federal Government has made a significant investment.

There are four program areas: local government, State government (executive), State government (legislative), and science and technology resources.

The local government program supports the establishment of statewide, regional, and national innovation networks to provide cooperative approaches for solving common problems with scientific and technical components. Examples of these statewide and regional groups are those in California, Georgia, Ohio, Texas, Oklahoma, Tennessee, and New England; national networks are the Urban Consortium, the Urban Technology System, and the Community Technology Initiatives Program. The interests of both rural and urban America are supported. At the national level, the networking facilitates the development of national research and development agendas relevant to local needs.

Local governments are experiencing unprecedented demands to assume decision-making and management responsibilities for a broad range of complex issues (e.g., energy, environment, etc.), many involving major scientific and technical components. This program emphasizes approaches to strengthen the capacity of local governments to identify their needs and ensure that research is appropriately targeted to important problems.

The State government program supports projects in individual jurisdictions and also fosters cooperation on a national basis to assist individual States in their capacity-strengthening efforts and to address critical issues of common concern. The increased complexity of issues continues to place a heavy burden on States' public management capacity. State governments need examples of successfully tested institutional mechanisms that can integrate into their executive or legislative policy management process.

The executive branch program emphasizes awards to national organizations representing State government (e.g., the National Governors' Association and the Council of State Planning Agencies). The program also supports regional groupings of States (e.g., Coalition of Northeastern Governors) to increase their capacity to obtain scientific and technical support.

The legislative branch program supports several States, including Arkansas, Connecticut, Oklahoma, and Virginia, to demonstrate ways to improve the access to, and use of, scientific and technical resources in State legislatures. Two projects begun with NSF funds were integrated into the staffing pattern of Minnesota and Wisconsin when each legislature assumed the full costs of these programs.

The science and technology resources program focuses on increasing the potential of various scientific and technical resource organizations (universities, Federal laboratories and industry) to serve more effectively the needs of State and local governments. The strategy is to use national organizations representing these scientific and technological resources.

One of the key elements of the S&T resources program is the Federal Consortium for Technology Transfer. The Consortium, with over 180 member laboratories, facilitates the transfer of existing science and technology to assist in the solution of problems. The laboratories are a resource for national and regional networks of local government (e.g., the Community Technology Initiatives Program and New England Innovation Group). The Federal Laboratory Consortium also shares computer data bases and conducts national and regional meetings with the user communities to ensure the broadest application of new information, research results, and successful technologies.

Experimental Program to Stimulate Competitive Research

This program has been established to improve the quality of science and increase the ability of scientists in eligible States to compete successfully for Federal research funds. The program reflects the perception that significant national as well as local benefits are derived from each State's participation in the national science enterprise. Through the program, NSF assumes responsibility for assisting institutions in States falling below specified minimum criteria to improve their competitive capability in science. At the same time, the States involved accept primary responsibility for their improvement.

During fiscal year 1979 broad-based *ad hoc* committees comprised of representatives of academic institutions, nonprofit and profit organizations, and State governments were established in seven states. Planning awards of $125,000 each were made available to each committee to analyze the status of science and technology in its State and develop a 5-year plan to improve the ability of local scientists to compete more successfully for Federal research funds. These plans will compete against one another in fiscal year 1981 for 5-year implementation awards amounting to approximately $3 million each.

Appropriate Technology

During fiscal year 1979, Congress directed the Foundation to begin a research program in appropriate technology. The program will begin funding research in fiscal year 1980.

Other appropriate technology activities that took place during fiscal year 1979 are discussed on the following pages under Problem-Focused Research/Problem Analysis.

Applied Research

The applied research program serves two purposes. First, it provides an open and flexible home for proposals from all fields of science and engineering involving the pursuit of applied research. Second, it recognizes selected targets of opportunity and responds by funding interrelated projects which together maximize these research opportunities.

The program includes two major sections. Applied social and behavioral sciences, concerned with social, economic, and policy processes, has supported work in areas such as regulation, inflation, unemployment, international trade, and behavior of service delivery organizations. In these studies a number of disciplines may play a role: economics, psychology, political science, law, finance, accounting, sociology, and operations research, to name a few.

Applied physical, mathematical, and biological sciences and engineering supports research in applied chemistry, physics, mathematics, geology, biology, and experimental psychology, as well as in engineering. Projects have been directed toward areas such as improved discovery and processing of mineral resources and developments in excavation technology; improved management of biological resources, both on land and in the oceans; and improved manufacturing processes. In both sections a significant number of projects involve more than one discipline.

Projects on the same or similar topics naturally form bodies of research taking on an identity beyond that of individual projects. NSF may respond to this natural grouping of projects by creating "coherent areas." These areas provide an organizational basis for interrelation of similar projects, conferences among principal investigators, and presentation of research to users and mission agencies. Current coherent areas being emphasized are: regulation; growth, income and employment; telecommunications; and production research and technology. A number of applied research studies are described on the following pages.

James Dyson at Florida State University, after examining the adequacy of research design and analysis procedures, has produced an assessment of available scientific studies on the impact of television. He concludes that the literature about learning (pro- and anti-social behaviors) was sound and convincing, but that poor research procedures lent little confidence to findings about the impact of TV on psychopathology or on the learning of stereotyping behaviors.

Research by Thomas F. Baldwin at Michigan State University describes the development and implementation of a two-way cable system and its effectiveness in urban administration. The project tested a mixture of interactive cable TV, videotape, and computer-assisted instruction for firefighter training. The system was found to be technically feasible, more effective than conventional training methods or one-way cable instruction, and less costly than live classroom training methods. A policy analysis conducted as part of the project suggests that operating costs for two-way cable applications are high enough so that franchise authorities will probably have to take the initiative if public service uses are to be made of two-way cable systems.

Sue E. Berryman at the Rand Corporation, evaluating non-entertainment applications of two-way cable television, studied a test of cable for videoconferencing among day care centers for the purpose of staff training. The research on increasing the quality of day care suggested that training via two-way cable may be less effective than other alternatives and that improving parents' expectations of day care quality and understanding of child care generally may be more beneficial than intensive training for day care staffs.

Sidney Davidson and Roman Weil at the University of Chicago have studied changes in financial statement income and in taxable income caused by changing the definition of income. Their report, *Income Tax Implications of Various Methods of Accounting for Changing Prices* is part of their research on implications of inflation accounting for public policy.

Research results from five separate NSF grants dealing with regulation of financial institutions were presented to senior officials from Government policymaking agencies, Congress, private industry, consumer groups, and academia at a 1979 conference sponsored jointly by NSF and the Federal Reserve Bank of Boston. The research findings added new, important information on the following aspects of financial institution regulation: creditor remedies, interest rate ceilings on loans and deposits, redlining, equal credit opportunity, and adequacy of reserve capital in banks and in non-life insurance companies. The papers have been published as a volume of the Federal Reserve Bank of Boston's *Conference Series*. The researchers included: James Barth, Joseph Cordes, and Anthony Yezer of George Washington University; Richard Peterson and William Dunkelberg of Purdue University; Robert Shay and William Brandt of Columbia University; Sherman Maisel of the University of California, Berkeley; and J.D. Hammond of Pennsylvania State University.

Catherine Lovell and colleagues at the University of California, Riverside, recently completed a study on the impacts of Federal and State mandates on local government. Based on a limited sample of local governments, they found that both Federal and State "direct order" mandates had increased four-fold since 1966. "Horizontal" mandates that weave across traditional local government functions have also increased. These mandates, especially the relatively new horizontal kind, superimpose or add new activities to traditional local government functions; about half are supported with local funds. The study makes no judgment about the desirability of mandates, but describes their growth and cost implications.

Research conducted by Kenneth L. Kraemer and staff of the Public Policy Research Organization at the University of California, Irvine, challenges currently popular theories about the impacts of computing and about the policies for the management of computing in organizations. The authors found in their intensive study of 42 American cities that computers have real payoffs for day-to-day government operations, but many of the payoffs for management and policymaking are yet to be achieved.

Modification of simple enzymes into species that can catalyze a range of synthetically important reactions could introduce a series of supercatalysts for a variety of chemical and biochemical conversions. Investigators at the University of Chicago, under the direction of Emil Thomas Kaiser, are closing in on the synthesis of a model enzyme system. The Chicago group took the enzyme papain—which is involved in hydrolysis reactions—and attached to it a synthetic flavin, an oxidation-reduction catalyst. In their best case their new molecule accelerates the rate of oxidation two to three orders of magnitude over the rate of nonenzymatic oxidation. This work also demonstrated the feasibility of tampering significantly with the active site of an enzyme as a catalytic species.

A major problem associated with higher-level automation of metal cutting processes is the need for a reliable and inexpensive means for monitoring tool condition. Walter D. Syniuta at Amtech, Incorporated, has suggested a way to develop a practical industrial cutting tool condition detector. The proposed solution to this problem is a micro-isotope tool wear detection system, in which a small radioactive particle is implanted at the edge of the allowable tool wear zone where it will be worn off as the tool is abraded. A radiation detector senses the presense or absence of the micro-isotope during the tool idle period, thereby providing a measurement of tool condition.

Problem-Focused Research

The goal of problem-focused research is to identify, acquire, and advance basic scientific knowledge and its applications in areas of great relevance to major societal problems. In fiscal year 1979 the program consisted of the following elements: earthquake hazards mitigation, alternative biological sources of materials, human nutrition, science and technology to aid the physically handicapped, integrated basic research, problem analysis, community water management, and chemical threats to man and the environment.

Earthquake Hazards Mitigation

Earthquakes are a worldwide problem, and the United States and other earthquake-prone countries have established cooperative programs for the exchange of scientific and technical information and for the exchange of data on earthquakes wherever they occur. In fiscal year 1979 this program participated in a number of cooperative international efforts, four of which are described here.

In accordance with a formal agreement between the Governments of the United States and Japan, NSF, the Japanese Science and Technology Administration, and the Japanese Ministry of Construction initiated a cooperative program to test large-scale structures by U.S. researchers and their Japanese counterparts. These activities are planned for the large test facility at Tskuba-New Town, which can simulate the effects of an earthquake on a full-sized, multistory building. Testing of reinforced concrete construction models will begin in fiscal year 1980.

In conjunction with the Committee on Scholarly Communication with the People's Republic of China of the U.S. National Academy of Sciences, NSF arranged for several exchange visits by scientists and engineers from both countries. These visits permit the scientists to exchange information and to become familiar with each other's work. During one such exchange visit, at the Second U.S. National Conference on Earthquake Engineering at Stanford University, the People's Republic of China released for the first time detailed technical information on the effects of the devastating Tangshen Earthquake of 1976.

A number of exchange visits have been completed by NSF staff and grantees and by Soviet scientists. These activities took place under NSF auspices in cooperation with U.S. Department of Housing and Urban Development. The NSF Working Group that visited the Soviet Union discussed five major topics: masonry construction, experimental testing of structures and components, methods for repairing and reinforcing existing buildings, analytical procedures to evaluate the strength of structures, and determination of building response by instrumenting typical buildings. NSF is also supporting a study by Columbia University of the problem of induced seismicity at the Nurek Reservoir, Tadjikistan, U.S.S.R. The Nurek Reservoir is located in an extremely seismically active area, and researchers have shown that an increased potential for seismic activity exists following rapid increases or decreases in the water level of the reservoir.

As part of a joint project between the University of California, San Diego, and the National University of Mexico, a synchronized strong-motion array was installed in Northwest Mexico near the Cerro Prieto, Imperial, Aqua Blanca, and San Miguel faults. This instrumentation array recorded the October 15, 1979, El Centro-Calexico Earthquake, which caused millions of dollars worth of damage to southern California and Mexico. The data from this earthquake should provide important information on earthquake source mechanisms, stresses, and maximum accelerations and velocities.

Alternative Biological Sources of Materials

This program is directed toward alleviating national dependence on selected scarce resources by making alternative biological sources available in the United States. Three particular topics were emphasized in the past year: biological conversion of lignocellulosic materials to useful chemicals; biological nitrogen fixation; and production of specialty chemicals from arid land plants (specifically, the production of natural rubber from the guayule plant).

The dramatic increase in the price of petroleum over the past several years has led to steep increases in the price of materials derived from this fossil resource. Among the critical materials are many polymers and basic industrial chemicals. Other fossil resources that may serve as raw material, such as coal and natural gas, have also exhibited similar price increases. More important, all of these fossil resources are limited.

An alternative to fossil resources as raw materials for the production of chemicals may be the use of biomass derived from plants and microorganisms. One possibility is the use of lignocellulosic biomass (e.g., wood), the constituents of which are lignin, cellulose, and hemicellulose, as a source of chemical feedstocks. Another possibility is the use of underexploited plants (such as guayule for producing natural rubber) and marine plants for obtaining valuable specialty chemicals and polymers.

During the past few years NSF-supported research has explored biological transformations of lignin which may make this ubiquitous substance more useful. At present, most of the lignin produced in pulping operations is burned; a key question is whether this material can be better used. In addition, new developments in biomass separation processes are producing "new lignins" which can be used in a host of applications not before attainable.

Research by Donald L. Crawford at the University of Idaho has shown that lignin can be degraded into useful materials

Biological processing. The bacterium *Streptomyces flavovirens*, shown in this scanning electron micrograph colonizing Douglas fir tissue, breaks down the cell walls, an early step in converting lignin into useful materials. (Photo by Donald Crawford/University of Idaho)

by certain strains of bacteria. Out of hundreds of bacterial strains isolated and examined for lignolytic activity, a number of them are quite effective lignin degraders. Crawford has determined that the actinomycete *Streptomycetes flavovirens* can attack and destroy the integrity of both lignified and nonlignified cell walls within the inner bark of Douglas fir. Although streptomycetes had been previously shown to colonize wood tissue, this is the first report that an actinomycete can decompose intact cell walls. Further work is now in progress to characterize the modifications of lignin in wood and to use the bacteria for beneficial industrial microbial conversions.

In a companion research activity at Virginia Polytechnic Institute, Wolfgang Glasser, Steven Drew, and Phillip Hall have shown that microbially modified lignins may have a potential and superior use in phenol-formaldehyde resins. Microbial action induces highly selective changes in lignin not achievable with conventional chemical techniques; these changes have a dramatic influence on the chemical reactivity and physical properties of the derived lignins. An analytical procedure developed to assess the subtle changes in the structure of lignin brought about by microbial action should have wide applicability in both academic and industrial research.

Human Nutrition

An estimated 70 percent of the food consumed in the United States is derived from highly refined ingredients and is processed during manufacture with various additives and supplements. However, effects of the life-long consumption of such processed foods on human health and performance have not been determined. The new human nutrition program supports research on the assessment of the nutrient value of processed foods through investigation of the physical, chemical, and biochemical changes that occur in these foods during cooking, processing, packaging, and storage. The foods to be studied will be the processed foods Americans frequently eat.

Science and Technology to Aid the Physically Handicapped

This new program supports research on the use of scientific and engineering developments to improve defective speech, visual, tactile, and hearing systems in persons afflicted with these impairments, and also to find ways to overcome locomotion and manipulatory limitations. The program involves researchers from many disciplines, including biomedical engineering, medicine, electrical engineering, and computer science, working with the active participation of handicapped persons on these problems.

Integrated Basic Research

The goal of integrated basic research is to improve the Nation's ability to deal with major problems where additional basic scientific understanding is likely to contribute to the solution of the problems. Joint support with the basic research program was provided for the following four topic areas during 1979.

Advanced Measurement Investigations

NSF supported a variety of "small science" projects that emphasized new methods for making scientific measurements. Two central themes emerged from the 45 projects: (1) improved techniques and instrumentation for observing the structure, properties, and characteristics of surfaces, and (2) improved methods for the study of biologically important molecules. The following are examples of the projects supported.

Albert Crewe at the University of Chicago is developing a high performance electron optical system for directly observing the interaction between heavy atoms and surfaces, as well as the behavior of aggregates of small numbers of atoms. This has obvious relevance for improved sensitivity of electron microscopes. This improved observational capability should benefit areas of research such as catalysis, where interactions between surfaces (the catalyst) and molecules sticking to the surface (the reactant) are important.

The availability of intense X-ray radiation from large synchrotrons has led to the new investigative technique of extended X-ray absorption fine structure. This technique is now being used by Keith Hodgson at Stanford University to explain structural locations of trace elements on proteins. In related work, John Baldeschwieler at the California Institute of Technology is investigating the feasibility of a system of generating X-rays which would not be dependent on large synchrotrons. If successful, this would enable researchers in geographically dispersed locations to conduct such experiments.

Biogeochemical Cycles of Carbon, Nitrogen and Sulfur

An increasing number of manmade environmental problems are suspected of causing changes in the global cycles of key elements. Examples are acid rain, stratospheric ozone depletion, and increasing levels of carbon dioxide in the atmosphere. Our lack of basic knowledge of ecosystems and mass and energy transfer between land and water limits our ability to predict future manmade effects. Of particular interest to this program is the exchange of carbon-containing chemicals among the atmosphere, water, and sediments, and the reservoir of carbon in the ocean. Under support from NSF's ocean sciences program and integrated basic research program, Wolfgang Berger at the Scripps Institution of Oceanography is studying chemical processes in the ocean that affect the accumulation of carbonate in ocean sediment. He is using sediments as a record of past drastic climate changes and studying their use as indicators of contemporary trends.

Deep Mineral Resources

Great mineral wealth is potentially available at depths of one mile or more below ground. Such resources could contribute decisively to long-range U.S. mineral availability if they can be recovered economically. The goal of this program is to increase the basic knowledge base necessary to permit technical evaluation of the potential for recovery of deep mineral resources. Research supported deals with geodynamics at active and fossil plate margins (affording insights on regional metallogenesis); rock mechanics for permeability enhancement and control for solution mining; and *in situ* leaching.

Population Redistribution

Population redistribution patterns are a major element in planning at regional and community levels, and unanticipated shifts in these patterns cause serious complications. This program provides an improved scientific basis for predicting such population redistribution patterns. Population forecasting seems to be at the stage of development that the field of statistics was before random variation and error were introduced into statistical procedures. The probability set with which a population forecast can be identified is elusive. Nathan Keyfitz at the Harvard Center for Population Studies is concentrating on the analysis of error in forecasts in order to give analysts a better view of the reliability of their forecasts and to improve the underlying assumptions in their techniques.

Problem Analysis

This program's objective is to determine whether a particular problem can be addressed by Federal research support and, if so, to determine the program options for NSF. Problem analyses evaluate external and internal suggestions for new areas of applied research support; topics selected take the form of new research initiatives or programs.

One such recommendation of a new area of applied research support—appropriate technology—was made by the House of Representatives Committee on Science and Technology. Appropriate technology includes technologies that are decentralized, require little capital investment, can be managed by their users, are in harmony with the environment, and conserve natural resources.

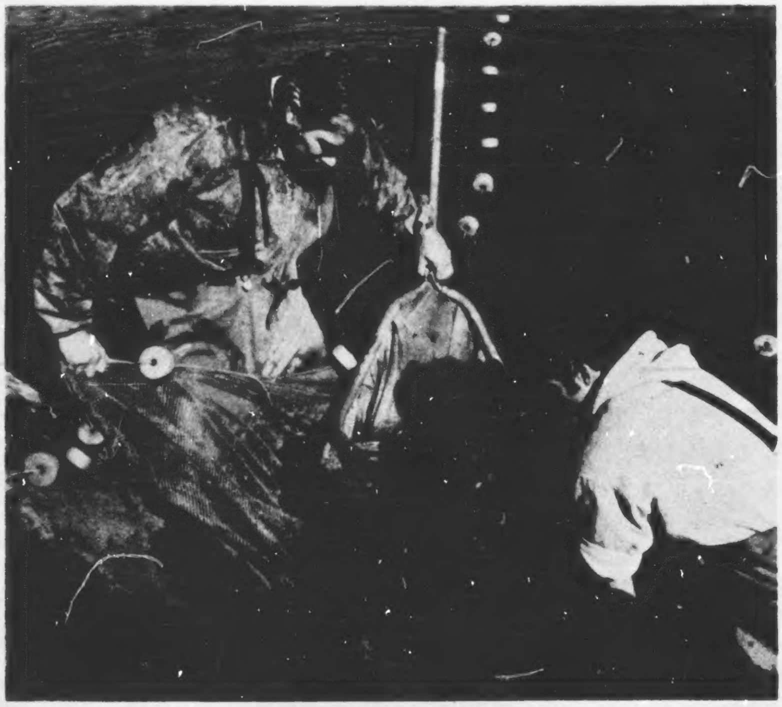
Using the results of surveys, workshops, and regional public forums, as well as consultation with other Federal agencies and input from interested citizens, NSF developed an appropriate technology program to begin in fiscal year 1980. The new program will address topics such as urban innovation; small-scale industrial technology; recycling, resource recovery, and conservation; rural revitalization; food and nutrition; and the impacts of appropriate technology on society, the economy, and technological development.

During fiscal year 1979 NSF submitted the final program plan to the House Committee on Science and Technology and supported planning activities designed to improve the operation of the program in fiscal year 1980. These included a workshop on the role of community and junior colleges in appropriate technology, organized by the American Association for Community and Junior Colleges.

Community Water Management

This program originated in NSF's regional environmental systems (1971-1975) and regional environmental management (1976-1978) programs, which dealt with water-related issues of land use, urban water resources, residuals, and risk management. The program, with many of its research results having moved into non-NSF development and demonstration stages, will not be continued in fiscal year 1980. In the current year it continued its focus on research to improve the management of community water resources to achieve and maintain acceptable levels of health, safety, and environmental quality at reasonable cost.

One example of this kind of research is a feasibility study of using the heated water from the cooling systems of electrical power generating stations to raise fish. In New Jersey, water from the heat exchangers of the Public Service Gas and Electric (PSG&E) coal-fired Mercer Generating Station on the Delaware River flows through experimental tanks where researchers have cultured freshwater shrimp, bass, catfish, eels, and rainbow trout. Officials of PSG&E are currently engaged in discussions with the New Jersey Public Utilities Commission regarding the expansion of the experimental facilities to full scale.



Aquaculture. Biologists from Trenton State College check the condition of a crop of freshwater shrimp whose growth in an experimental aquaculture system was enhanced by warm discharge waters from an electric power generating plant.

Chemical Threats to Man and the Environment

In its final year as an NSF program, the chemical threats to man and the environment activity completed support of research on the prediction, identification, characterization, and control of hazards resulting from chemical compounds in the environment. NSF has supported a multi-year collaborative effort involving the Lawrence Livermore Laboratory, the San Francisco Bay Area Air Pollution Control District, and the National Aeronautics and Space Administration's Ames Research Center to develop and validate a regional air quality model that accounts for photochemical effects. By collecting, organizing, and mathematically generalizing field measurements of pollutants and taking into account topography, meteorological settings, land-use patterns, and population distribution, the Livermore Regional Air Quality Model (LIRAQ) has made it possible for environmental planners and regulatory officials to predict or assess the impact of a specific activity on the air quality of a region.

LIRAQ is currently being validated for the Willamette Valley of Oregon, where more than 70 percent of the Nation's grass seed is produced. Grass seed residues are routinely burned each season, but intense local public concern about the effect of the smoke from this source and of local lumber mill waste burners on the air quality in the Valley has made it necessary for State officials to seek better strategies for lessening the environmental impact of these practices. Charles Craig at Oregon State University has received support to feed Willamette Valley field emissions data, local meteorological data, and air quality data into LIRAQ. LIRAQ will then be verified and transferred to Oregon's Department of Environmental Quality. It will be used as an operational air quality planning tool by the State of Oregon in developing quantitative methods for managing the smoke generated from open field and slash burning of grass fields and timber industry wastes.

111

Scientific, Technological, and International Affairs

6

The Foundation's programs in Scientific, Technological, and International Affairs (STIA) monitor the national and world scientific and technological enterprise. The programs collect and interpret data and research and analyze important S&T (science and technology) policy issues. They also promote the exchange of information through scientist-to-scientist links in the world scientific community and support research into the properties and transfer of scientific and technological information.

The main components of STIA are: (1) policy research and analysis; (2) science resources studies; (3) science information and technology; and (4) international cooperative scientific activities. These combined efforts help policymakers in the public and private sectors assess alternative S&T policies and programs.

Policy research and analysis provide an institutional framework for performing short- and long-term studies, analyses, and assessments of S&T-related policy issues, particularly with respect to Federal roles—their impact and their effectiveness. This is accomplished through an extramural research program that is coordinated with ongoing intramural staff analyses focused on the concerns of policymakers. The information and analyses produced by these activities are disseminated to users in both the public and private sectors.

Science resources studies collect and analyze data on U.S. human and financial resources for scientific and technological activities. In fiscal year 1979 NSF issued 30 reports providing overviews of the quantity, quality, and direction of the U.S. scientific and technological enterprise.

Information science and technology activities strengthen fundamental understanding of the properties and structure of information; they contribute to the store of scientific and technical knowledge that can be applied in the design of information systems. In FY 1979 this research program emerged more strongly in intent and substance and initiated awards to attract qualified new researchers to the evolving field of information science.

International cooperative scientific activities increase science and technology benefits to the United States through a sharing of research approaches, costs, facilities, and results. During fiscal year 1979 this program supported cooperative relationships between U.S. and foreign scientists and institutions by advancing U.S. participation in international scientific organizations, joint programs and projects, and individual exchanges in research. Such scientific activities serve the needs of U.S. science and also support U.S. foreign policy objectives.

NSF's planning and evaluation activity, also presented in this chapter, responds to the Foundation's need to improve the management of its activities and to appraise their adequacy, impact, and accomplishments in relation to overall NSF objectives.

Table 10
Scientific, Technological, and International Affairs
Fiscal Years 1977, 1978, and 1979

(Dollars in Millions)

	Fiscal Year 1977		Fiscal Year 1978		Fiscal Year 1979	
	Number of Awards	Amount	Number of Awards	Amount	Number of Awards	Amount
Policy Research and Analysis	82	$ 3.50	88	$ 5.57	137	$ 5.46
Science Resources Studies	54	2.79	48	2.51	52	3.07
NSF Planning and Evaluation	54	1.34	33	0.88	23	0.97
Information Science and Technology	57	4.54	50	4.97	40	4.43
International Cooperative Scientific Activities	684	8.49	578	9.85	529	11.45
Total	931	$20.66	797	$23.78	781	$25.38

SOURCE: Fiscal Years 1979, 1980, and 1981 Budgets to Congress—Justification of Estimates of Appropriations (Quantitative Program Data Tables).

Policy Research and Analysis

Policy research and analysis activities include internal staff analyses and external studies of science and technology policy issues that are of interest to NSF, organizations within the Executive Office of the President (such as the Office of Science and Technology Policy and the Office of Management and Budget), other agencies, and the Congress.

The program is divided into five areas: socioeconomic effects of science and technology; environment, energy, and resources; innovation processes and their management; technology assessment and risk analysis; and special projects. Activities in the past year are described on the following pages.

Socioeconomic Effects of Science and Technology

This program element concentrates on the relationship of science and technology to economic performance and the quality of life, the effects of Government actions on the relationship, and improved methods for generating information on those topics. Projects included:

- Measurement of private and social returns from technological innovation—a series of related studies funded under grants or contracts to the University of Iowa, Purdue University, Foster Associates, and Robert R. Nathan Associates.
- Measurement of the effects of private and public sector funding for R&D and technological innovation on productivity growth—several related studies conducted by the Center for Naval Analyses, National Bureau of Economic Research, Mathtech, and RAND Corporation.
- Assessment of the role of R&D and technological innovation and international diffusion of technology on the U.S. international competitive position, a series of studies by the National Academy of Engineering, University of Pennsylvania, University of Washington, and Charles River Associates.

Environment, Energy, and Resources

This program element supports studies of scientific or technological developments that have implications for Federal environmental, energy, and resource policies and where Federal policies in these areas influence S&T. Projects included:

- A scientific and technical evaluation of the Environmental Protection Agency's planning process for wastewater treatment facilities grants. The Boston case study was the subject of final contractor reports received in February 1979. The study examined the operation of the national program with a view toward developing recommendations for possible legislative or administrative improvements at the national level.
- Environmental and safety regulation and technological change in the U.S. chemical industry, by the Center for Policy Alternatives, Massachusetts Institute of Technology. This study found that the regulatory stimulus for technological change is complex, time-dependent, and variable, and that informal regulatory controls such as publicity or consumer attitudes are as important as more formalized rulemaking.
- The future regional distribution of national synthetic fuel capacity, by Resources for the Future, Inc. This study examined the factors that influence the location of facilities to produce synthetic liquid and gaseous hydrocarbons from either coal or oil shale, and analyzed where such plants are likely to be placed regionally. The report suggests how the information developed could be used in forecasting and modeling regional energy development and facility siting. It also provides insight into how the pace of synthetic fuel development as well as its regional mix can be affected by policy instruments.

Innovation Processes and Their Management

This program supports studies to improve understanding of the incentives and disincentives affecting innovation processes and identifying leverage points for public policy action. Specific areas of concern are: innovation processes in industry and in State and local government; the role of R&D in technological innovation; the role of individuals and institutions in innovation; and the commercialization and diffusion of innovations. Projects included:

- An innovation diffusion symposium to exchange ideas for improving the delivery of municipal services. Participating public interest groups and professional associations included the American Public Works Association, the National League of Cities, and the National Governors Conference.
- At a workshop conducted by the Center for Interdisciplinary Study of Science and Technology of Northwestern University, economists, sociologists, political scientists, and management scientists evaluated current research on the diffusion of innovation in terms of its usefulness to Federal policymakers. They identified gaps in existing knowledge and in current Federal research support programs. Alternative approaches for diffusion research were proposed.
- A study by the Massachusetts Institute of Technology which

defined situations where users initiate innovation in private industry. These situations, particularly common in small high-technology businesses, constitute an interesting and effective variation from standard R&D practice.

Technology Assessment and Risk Analysis

The primary goal of this program is to help decisionmakers plan for impacts and risks associated with the implementation of new technologies—especially those technologies that may require policy intervention. Short-term studies are directed at emerging science and technology issues that may result from questions about the impacts and risks associated with technology. Long-term research focuses on: (1) generic questions of technology assessment and risk analysis; (2) understanding how information about technological risks and benefits is used in policy decisions; and (3) ways in which the knowledge base for those decisions can be improved and made more useful.

Projects completed in 1979 examined the impacts of widespread uses of industrial robots; time-of-use pricing methods for electric energy; and technologies for computer-assisted makeup and imaging systems as alternatives to the traditional printed media. Another project examined patterns of use and choice to identify future preferences for the automobile.

Special Projects

Special projects result from policy study requests made by the Congress, the Office of Science and Technology Policy, and the Office of Management and Budget, or other Federal agencies. Projects include:

- The *Science and Technology: Annual Report to the Congress* was submitted in August 1978, as required by the National Science and Technology Policy, Organization, and Priorities Act of 1976. This first report examined the economic foundations for the Government's role in science and technology and discussed a number of additional issues, including the contribution of R&D and innovation to productivity. A second report was prepared in 1979, with publication planned in early 1980.
- *The Five-Year Outlook for S&T* addresses mid-range issues of interest to the scientific community and the public. This is a substantial effort, assisted by the National Academy of Sciences, other Federal agencies, and individuals. Publication is anticipated in early 1980.
- The Domestic Policy Review on Industrial Innovation involved extensive NSF participation in direct analyses and in support of a series of related studies. Topics addressed included Government policy instruments such as taxation, patent rights, Government procurement, regulation, antitrust, and collective bargaining.
- The Nonfuel Minerals Domestic Policy Review reports on R&D opportunities in the nonfuel minerals sector. It identifies key problems and opportunities across the minerals/materials cycle and points to several issues that will require further analysis.
- An analysis of developing country national papers aided in the formulation of the U.S. position for the U.N. Conference on Science and Technology for Development in August 1979. The analysis ascertained needs and action priorities expressed by developing countries in the following areas: food and agriculture; natural resources; health, human settlement, and environment; transportation and communications; and industrialization.

The projects described illustrate the nature and scope of work conducted and funded by NSF in the policy research and analysis area. A cumulative listing and brief abstract of the studies completed through the end of fiscal year 1979, together with ordering information for individual reports, is available free from the National Science Foundation, Directorate for Scientific, Technological, and International Affairs, Division of Policy Research and Analysis, Washington, D.C. 20550.

Science Resources Studies

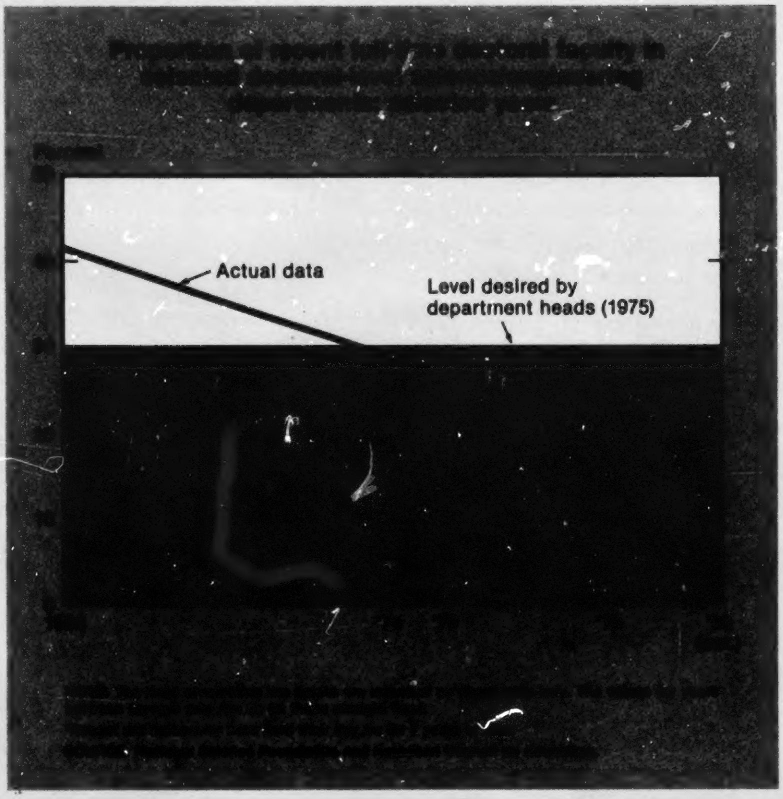
The science resources studies (SRS) program develops timely overviews of the Nation's human and financial resources for scientific and technological activities. Program functions include: (1) development and maintenance of quantitative S&T information bases; (2) analysis of data that illuminate current issues and identify factors responsible for prospective supply and utilization patterns; and (3) preparation of special studies carried out at the request of Federal policymakers such as the Office of Management and Budget, the Office of Science and Technology Policy, or various Congressional committees.

Program activities are divided into three elements: scientific and technical personnel, funding of science and technology, and modeling and science and technology indicators. The program publishes 30 reports annually. In fiscal year 1979 SRS began a major revision of its survey and publication schedule. First, to lessen the burden on private sector respondents, it was decided that full-scale survey questionnaires will be used only in alternate years, with abbreviated versions used in "off" years. Second, with some sets of final reports consolidated, the number of final reports was reduced, creating fewer, though broader and more integrated, documents.

Scientific and Technical Personnel

NSF generates information on the supply and utilization of scientists and engineers through periodic or *ad hoc* surveys of individuals and of employers. The information is used to monitor current labor markets, to improve the understanding of factors that impinge on supply and utilization, and to project future labor market conditions.

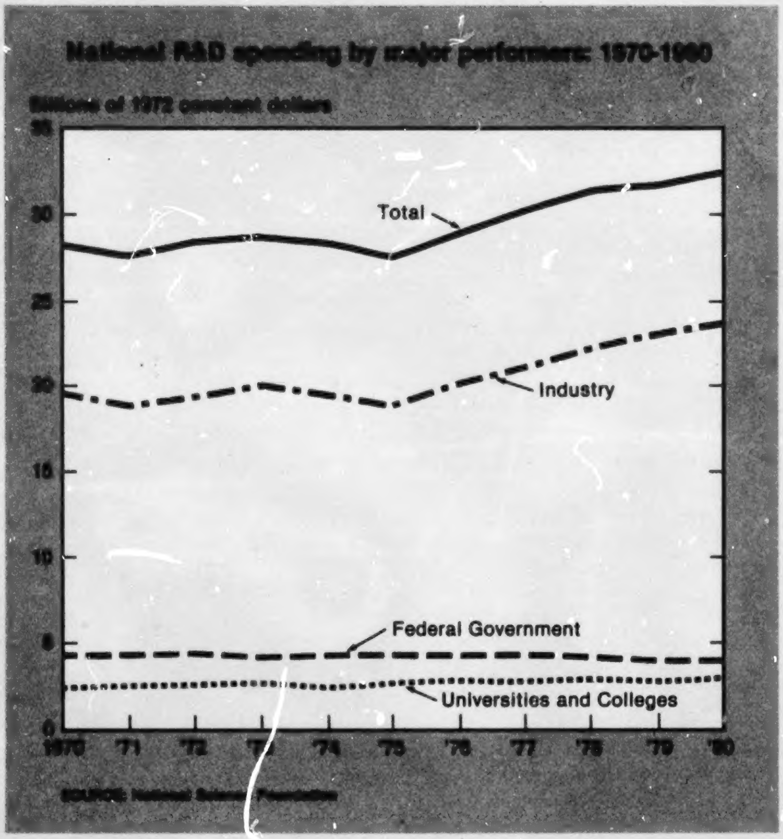
Recent Labor Market Trends. Information from a set of three separate surveys highlighted the following: In 1978, the science and engineering (S/E) labor force—those employed plus those seeking employment—numbered 2.5 million, evenly divided between scientists and engineers. It grew by 2 percent during the 1976-78 period, contrasted with a 7-percent growth between 1974 and 1976. S/E unemployment in 1978 amounted to about 1.5 percent. Despite the overall improvement, the number of employed physical, environmental, and social scientists declined by about 6 percent between 1976 and 1978. However, the fields of psychology and computer science reported very high rates of employment growth—over 20 percent between these 2 years. Employment opportunities for newly graduated scientists and engineers from the 1974 and 1976 graduating classes improved. Among bachelor's degree recipients, the unemployment rates 2 years after graduation declined from 8.2 percent in 1976 to 3.9 percent in 1978; among master's degree recipients unemployment declined from 4.4 percent in 1976, to 3.8 percent in 1978. The increase in employment opportunities for bachelor's degree recipients was evident in all science and engineering fields; among master's degree recipients, improvement occurred in all but the life and social sciences.



Academic employment opportunities. Demographic conditions combined with an unfavorable age distribution of academic faculty have given rise to serious concerns about future job openings in academia for scientists and engineers. NSF has been monitoring this situation since the mid-1960's. A survey conducted for NSF by the Higher Education Panel of the American Council on Education found that total full-time doctoral faculty increased over 14 percent between 1968 and 1978, but that recent faculty doctorates—those who have held that degree for 7 years or less—decreased by 39 percent.

Industrial employment opportunities. An NSF survey showed that industries whose relative concentration of scientists and engineers was "high" in 1977—such as petroleum refining, chemicals, and electrical equipment—grew at a significantly faster rate, measured by total employment, than industries with "low" concentrations—such as apparel, leather products, and printing and publishing. Industries with higher S&E concentrations showed total employment gains of 17 percent from 1965 to 1977, and 4 percent from 1970 to 1977. Industries with low S&E concentrations grew at rates of 4 percent from 1965 to 1977 and showed a slight employment decline from 1970 to 1977.

Future doctorate supply and utilization. Projections indicate that the number of doctoral scientists and engineers in the full-time labor force may expand from 280,000 in 1977 to about 412,000 by 1987. By contrast, the number of science-related jobs held by doctorates is projected



to rise from 255,000 in 1977 to about 342,000 in 1987. If these growth patterns are realized, about 70,000 doctorates would be working in jobs not directly related to their training in science and engineering, compared with about 25,000 so employed in 1977. New (1977-87) doctorates in all broad fields in S/E positions are expected to be less concentrated in academia than all S/E doctorates in the 1977 labor force—57 percent for the latter vs. 35 percent for the former. New S/E doctorates are projected to be more concentrated in nonprofit organizations—7 percent for the 1977 labor force vs. 16 percent for new doctorates, and in industry—25 percent of the 1977 labor force vs. 32 percent of new doctorates.

Funding of Science and Technology

National R&D funding data are collected through periodic surveys in the major economic sectors—Federal, industry, university-college, and nonprofit. The data are analyzed for science policy implications, with special attention given to the causes and effects of any changes in the level and distribution of R&D financing and performance.

Funding for total U.S. R&D rose by 11 percent in 1979 and is expected to continue to increase in 1980 to $58.5 billion—more than doubling the amount spent in 1970 and a 10-percent increase over 1979. However, with inflation taken into consideration, the average 10-year rate of increase amounts to only 1 percent and the 1979 to 1980 rise to 2 percent. A major characteristic of R&D funding has been the substantial growth of energy research and development expenditures by both Federal and private industrial sources.

Small R&D firms. Although the Federal Government is the major source of funds for research and development, industry is the largest R&D performer, spending some 70 percent of the National R&D total each year. In 1980 industry R&D expenditures are expected to reach a high of $42.4 billion, two-thirds of which will be from industry's own funds. The small R&D firms are important contributors to the industrial R&D effort. Although their dollar investment is small compared to the industry total, they are believed to be relatively more innovative than the larger R&D performers. There have been indications that many small, technically oriented firms have been having difficulty coping with some of the problems confronting them, causing a significant number to fail. The continued loss of these firms could result in an important reduction in the U.S. scientific and technological capability. In response to this concern, NSF conducted a survey of problems facing small R&D firms. An analysis of the results of the survey of some 1,230 firms showed that of eleven problem areas firms were asked to rate, almost 70 percent reported "providing competitive salaries and benefits to employees" and "maintaining an adequate volume of R&D work" as areas of major concern. Firms were found to be particularly sensitive to major changes in direction or volume of Federal spending. They were found to be highly competitive and to exist in an atmosphere of uncertainty over personnel turnover, workload, Government regulations, and obtaining adequate capital. A second report explored in greater detail, through a series of interviews, five of the major problems uncovered by the survey.

University and college R&D. Academic institutions are expected to spend a total of $5.5 billion for research and development in 1980, an increase of 10 percent over 1979, but only 2 percent when adjusted for inflation. This matches the average annual real growth shown by NSF surveys for university and college R&D expenditures over the 1970-79 period. Although Federal agencies continue to provide universities with the major portion of their funds for research and development, this portion is expected to show a decrease in 1980 to 67 percent from a high of 74 percent in 1966. While academic institutions continue to concentrate the largest portion of their R&D effort on basic research, that portion has declined. In 1980, they are expected to spend 71 percent of their total Federal and non-Federal R&D funds for basic research compared to 77 percent a decade earlier.

Science Indicators

The National Science Board's 11th Annual Report, *Science Indicators—1978,* was prepared by NSF staff for transmittal to the President and the Congress. It is the fourth in a series devoted to the assessment of U.S. science and technology through quantitative indicators. The indicators are grouped under: international science and technology, resources for R&D, resources for basic research, industrial R&D, and scientific and engineering personnel. Increased emphasis has been placed on pointing out alternative interpretations and limitations of data. Indexes to subjects and to data relevant for selected policy issues are a new feature.

Research is moving forward on several fronts related to the development of new science indicators for measuring the impacts and outputs of science. The first grants in this new research program were made in FY 79. They covered such areas as: literature citation methods to identify advances in science; productivity indicators; technology performance indicators; relationships among academic research funding, staffing, and scientific literature; and statistical studies of models of the S&T enterprise.

As the science indicators work becomes more analytical, areas have been identified that call for in-depth analysis, such as patent statistics as a measure of technological activity or R&D output. Four experts from economics and patent law were asked to evaluate patent data in *Science Indicators* reports and drafts, to describe appropriate and inappropriate applications of such data, and to suggest areas where further investigation might be profitable. Their reports are being prepared for publication by NSF in 1980.

NSF Planning and Evaluation

The planning component of this program supports research and policy analysis to strengthen NSF's ability to plan its activities and deal with specific policy issues. In assisting the policy and long-range planning activities of the NSF Director and the National Science Board, the program supports a small number of extramural studies. During the past year, contracts were awarded for:

- A study of the needs, supply, and use of scientific instrumentation and research equipment in research universities.
- A study of the prospects for new academic science positions in Western Europe and Canada from 1980-2000 and their policy implications for the United States.
- A workshop on the role of organized research units for academic science at research universities.
- A study of changes in the patterns of hiring scientists and engineers at non-doctoral public colleges.
- A study of factors affecting research vitality in the mathematical sciences.

Among the earlier activities that were completed in the past year were:

- Publication and redistribution of a report, *Increasing the Participation of Women in Scientific Research.*
- A report, *Interdisciplinary Research Management: Research Needs and Opportunities.*
- Several special analyses on academic and scientific manpower bearing on the availability of positions for young investigators. Data bases kept by the National Research Council and the American Association of University Professors were used.
- A report on *Measuring and Forecasting the Cost of Performing Research in the Biological Sciences.*
- A final report on *Regional Forums of the National Science Board: An Experiment with Public Participation in Science Policy Formulation.*

The program has continued to assess the factors that affect the support of science in the United States. Policy issues arising in connection with the funding and performance of scientific activities, and their role in the achievement of NSF's goals, comprise a long-term concern of the program. Examples of key issues are: the allocation of support among research areas; the relation of research to national goals; the economic and cultural consequences of science support; more effective mechanisms for the support of science; and the impact of economic and other societal factors on science.

Evaluation studies provide the NSF Director with information on the effectiveness of major NSF programs. They form the basis of his oversight responsibilities in these areas and provide groundwork for budgetary or policy decisions about program expansion, curtailment, or reorientation. Program evaluations are designed internally; they are often carried out by contractors.

In 1979 an evaluation of the minority institutions science improvement program (MISIP) was completed. The goals of the program are to improve science instruction in minority institutions and to increase the flow of minorities into science careers. The evaluation addressed the issues of four hypotheses: *Hypothesis 1:* MISIP grants will result in increased institutional capability to conduct quality science education programs. *Hypothesis 2:* MISIP grants will result in increased minority participation in science education and science degree programs. *Hypothesis 3:* Research initiation grant recipients will continue research after their grants expire and will have greater success in obtaining research support. *Hypothesis 4:* There are certain institutional and programmatic variables conducive to progress toward MISIP goals. Data used in the evaluation included NSF files, Higher Education General Information Survey, a mail survey of 225 institutions that were eligible to participate in the MISIP program, and field interviews. Data were analyzed to detect if there were statistically significant differences between MISIP-funded and MISIP-eligible, nonfunded institutions between 1969-70 and 1975-76.

The results were: *Hypothesis 1.* In general, both MISIP and non-MISIP institutions improved the quality of their faculty, instruction, and facilities. The only statistically significant difference was that MISIP institutions had a greater proportion of schools with increase in career-counseling by faculty than MISIP-eligible nonfunded institutions. *Hypothesis 2.* MISIP-eligible nonfunded schools had a statistically significant greater increase in percentage of science degrees, out of the total earned degrees, than MISIP-funded schools. However, since the MISIP program has had an average of only 2 years to make an impact, it is unlikely that it could have any substantial impact on science degrees in this short time. While this is an important issue for evaluation, definitive results cannot yet be determined. *Hypothesis 3.* There has been little change in the success ratios, i.e., in both the ratio of number of successful proposers to number of proposers and the ratio of number of awards to number of proposals; however, the number of investigators submitting proposals and the numbers getting awards have increased substantially. *Hypothesis 4.* Analysis of the responses to the survey questions on institutional and programmatic variables conducive to progress toward MISIP goals leads to the expectation that strong support from the academic administration and good interdepartmental cooperation are essential for a successful MISIP grant.

Information Science and Technology

Research in information science is entering a new, more broadly based phase that integrates methods of studying problems that have arisen independently in many fields of science. Recent advances in information technology have both stimulated more research on old problems and opened new research areas. NSF's information science and technology programs were restructured in fiscal year 1979; the descriptions of the research areas on the following pages indicate the new emphases that guided the activities in the past year.

Standards and Measures

This program is concerned with defining attributes of information such as quantity, complexity, meaning, use, and value, and their relation to the structure, organization, transfer, analysis, and use of information collections. It also develops objective measures of performance for human beings and information processing systems that organize, identify, analyze, and retrieve information. The measurement of information, and the connection between information and the process of measurement, are important aspects of each of the research areas described below.

- Mathematical models of information system use are being developed by University of California, Los Angeles, researchers to permit testing of hypotheses.
- At Ohio State University research underway will apply a theory of information flow and analysis to gain better understanding of the use of information in practical situations of decisionmaking.

The Structure of Information

Research supported by this program examines the structural characteristics of information collections and their relationships to the functioning of information systems. Receiving special emphasis are studies of the relationship between form and content in language, the connection between statistical theories of information and structural properties, and the representational structure of information patterns in text, image, and numerical archives. Examples of projects begun in 1979 include:

- Cornell University work in mathematical modeling in automatic information retrieval, undertaken to provide new knowledge regarding retrieval processes.
- A project by Columbia University researchers which seeks to determine what categories and relations of categories express information and how information can be checked for truth-conditions.

Behavioral Aspects of Information Transfer

This category is concerned with research into the abilities of people as information processors. The general principles of cognitive processing and retrieval—including selected aspects of memory, learning, problem solving, and information pattern recognition—underlie the human ability to process information. The development of effective machine-based and interactive information systems obviously depends on an understanding of the human factors involved in the interactions between people and the inanimate information systems with which they interact. When information transfer involves more than one person interacting with a constituent of an information system, new problems arise. Because large information systems are generally used by many people, they may be most effective for the hypothetical average user but not as effective as they could be for any particular user. This requires the study of objectively measurable properties of human-human information transfer. Recently supported projects include:

- The study of text processing effects and memory recall by Yale University scientists concerning the capability of mechanisms to perform inferences similar to those which comprise human reasoning.
- A University of Texas project that addresses the representation, retrieval, and reorganization of conceptual information in an effort to provide analyses of baseline information against which the human system can be compared.

Infometric Models

Information, with its increasing role in society, has become interwoven with technology and the economy in a complex way. These interactions, and the pervasive effect of rapidly changing microelectronic and telecommunications developments, call for a better understanding of the role of information in economic theory and for the development of the analytical apparatus and data to make it possible to predict as well as trace the impact of technological and regulatory changes. The following two projects are among those supported by this program in 1979:

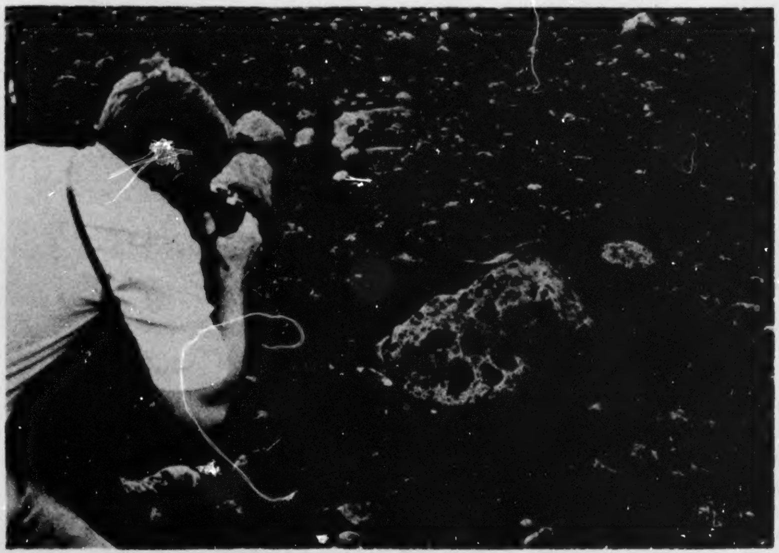
- Research by the University of Pennsylvania using mathematical economics to analyze aspects of information in microeconomic theory and to study relationships between information and microeconomics.
- Network modeling simulation performed by University of Pittsburgh investigators. By examining the economics of using resource-sharing networks for information transfer, the researchers intend to provide information system managers with a tool for determining whether it is advantageous to participate in such a network.

International Cooperative Scientific Activities

NSF's international cooperative scientific programs have a dual purpose. They support the U.S. science enterprise by acquiring knowledge about scientific activities in other countries and by facilitating access to research environments and facilities abroad. At the same time, these programs build and strengthen international links between the United States and many other countries of the world.

During 1979 NSF continued to support U.S. scientists' collaborative work with foreign colleagues on a bilateral basis. Cooperation took place both under formal bilateral science agreements and through informal arrangements between NSF and foreign government agencies. The activities included joint research projects in basic and applied fields of science, seminars or workshops, and scientific visits. Cooperating foreign scientists came from three groups of countries: advanced, industrialized countries; developing countries; and countries of Eastern Europe and the U.S.S.R.

Advanced countries with which the Foundation has joint programs include



In the field. A U.S. scientist studies rock samples as part of a cooperative science project at the Fuego Volcano in Guatemala.

Australia, France, Italy, Japan, and New Zealand. In one recent activity, U.S. and French investigators collaborated on a project related to solar energy materials. They jointly evaluated refractory materials as high-temperature selective coatings for photothermal conversion of solar radiation. In another cooperative venture, scientists from the United States and Australia jointly studied the properties of the carbon monoxide-to-copper adsorption system using three experimental techniques—low energy electron diffraction, Auger electron spectrometry, and infrared reflection spectroscopy. The project is part of a long-term effort to increase understanding of the interaction of gases at metal surfaces.

Programs with developing countries include activities in Africa, Latin America, and East Asia, involving both middle- and low-income countries. In Latin America NSF supported a U.S. scientist in a joint project with Brazilian colleagues on surface physics and surface properties of materials. The scientists have coordinated experiments at their respective institutions and have used complementary approaches to study thermodynamic and superfluid properties at low temperatures of monolayers and submonolayers of rare gas atoms on homogeneous surfaces. The research is of fundamental scientific interest and has, as well, potential application in electron emission devices, photosensing systems, and semiconductor junction devices.

In a project to study continental volcanic sediments, U.S. scientists working at the Fuego Volcano, one of the most active volcanos in the Western Hemisphere, developed information on the sedimentology of volcanic deposits that will increase understanding of ancient depositional environments. Research results may also aid in controlling the hazardous mudflows that occur when torrential rains fall in areas with loose volcanic debris.

On the other side of the globe, U.S. scientists have been studying traditional soybean processing techniques in Taiwan. They worked with researchers from National Taiwan University to determine the ideal conditions for extracting crude protein molecules, the major nutritional component of soybeans.

In Eastern Europe, U.S. scientists collaborated with scientists in Bulgaria, Hungary, and Romania. In one project, scientists from the United States and Hungary developed a system for producing a repetitively pulsable traveling wave laser. A component of the project was successfully patented in the United States.

Under the U.S.-U.S.S.R. Agreement on Cooperation in the Fields of Science and Technology, NSF oversees activities under ten joint working groups. These working groups address computer applications to management, chemical catalysis, corrosion, earth sciences, electrometallurgy and materials, heat and mass transfer, microbiology, physics, polymers, and science policy. In one of the areas, cryogenic materials and weldment, the two sides have exchanged steel and aluminum alloys and welding consumables for comparative evaluations of techniques and properties.

In addition to cooperative science programs with the U.S.S.R. and countries of Eastern Europe, the Foundation continued to support scientist exchanges organized by the National Academy of Sciences and the national academies of the U.S.S.R., Bulgaria, Czechoslovakia, the German Democratic Republic,

Library facilities. Research at the International Institute for Applied Systems Analysis in Vienna focuses on problems common to industrialized nations.

Hungary, Poland, Romania, and Yugoslavia.

In 1979, U.S.-owned foreign currencies excess to U.S. Government needs in Egypt, India, and Pakistan were available for cooperative science activities. NSF used special foreign currency (SFC) to support research projects, joint seminars, and travel in those countries. One activity was a symposium on mechanics of alluvial channels. Attended by engineers and scientists from U.S. and Pakistani institutions, this meeting reviewed and evaluated 5 years of progress in field research, instrument development, and data analysis activities on the link canals of the Indus River basin.

SFC also helped to support U.S. participation in major multilateral research projects, notably the international Monsoon Experiment, or MONEX. During the year, a major observation and data collection effort took place over the Indian Ocean, India, and East Asia. NSF also continued its use of SFC to support translations of foreign scientific books, papers, and monographs for use by the U.S. scientific community. Contractors in India, Pakistan, and Egypt translate approximately 50,000 pages of material annually. Almost half of the material translated was from Russian language information sources; the rest was from German, French, Polish, Dutch, Japanese, Arabic, and Italian sources.

In 1979, through the National Academy of Sciences, NSF continued to support U.S. participation in international scientific organizations, especially the International Council of Scientific Unions and the International Institute for Applied Systems Analysis (IIASA). IIASA, located near Vienna, Austria, was chartered to apply systems analysis methodology to the study of common problems of industrialized nations. IIASA is nongovernmental, with membership composed of scientific institutions from the United States, the Soviet Union, Canada, Japan, and the countries of Western and Eastern Europe. IIASA research focuses on energy systems, resources and environment, food and agriculture, human settlements and services, management and technology, and system and decision sciences.

A major evaluation of the benefits to the United States of participation in IIASA was completed during the year. The evaluation consisted of four principal elements: a peer review of IIASA research reports; a survey of the U.S. recipients of IIASA reports and U.S. attendees of IIASA conferences; papers by outside experts assessing IIASA's progress toward its original goals; and a survey of U.S. scientists who have worked at IIASA. The evaluation showed real benefits to the U.S. science community of participation in IIASA and identified methods for further increasing these benefits.

NSF awards under the international travel grant program permit participation by U.S. scientists in important international meetings held abroad. At the beginning of 1979, to reduce costs and improve program efficiency, emphasis was shifted to support group travel grants to professional societies, universities, and other nonprofit organizations for coordination of U.S. participation in international meetings abroad. A limited number of individual awards are still made to U.S. scientists invited as organizers or keynote lecturers at major international meetings and to young scientists invited to participate in Advanced Study Institutes held by the North Atlantic Treaty Organization. During 1979, a total of 713 U.S. scientists were supported by the travel grant program.

Appendix A

National Science Board, NSF Staff Advisory Committees and Panels

NATIONAL SCIENCE BOARD

Terms Expire May 10, 1980

Jewel Plummer Cobb, *Dean and Professor of Biology*, Douglass College, Rutgers—The State University of New Jersey, New Brunswick, New Jersey.

*Norman Hackerman, (Chairman, National Science Board), *President*, Rice University, Houston, Texas.

W. N. Hubbard, Jr., *President*, The Upjohn Company, Kalamazoo, Michigan.

Saunders MacLane, *Max Mason Distinguished Service Professor of Mathematics*, University of Chicago, Chicago, Illinois.

*Grover E. Murray (Vice Chairman, National Science Board), *University Professor*, Texas Tech University and Texas Tech University School of Medicine, Lubbock, Texas.

Donald B. Rice, Jr., *President*, The Rand Corporation, Santa Monica, California.

L. Donald Shields, *President*, California State University, Fullerton, California.

James H. Zumberge, *President*, Southern Methodist University, Dallas, Texas.

Terms Expire May 10, 1982

Raymond L. Bisplinghoff, *Vice President for Research and Development*, Tyco Laboratories, Inc., Exeter, New Hampshire.

Lloyd M. Cooke, *Vice Chairman*, Economic Development Council of New York City, Inc., New York, New York.

*Herbert D. Doan, *Chairman*, Doan Resources Corporation, Midland, Michigan.

John R. Hogness, *President*, Association for Academic Health Centers, Arlington, Virginia.

William F. Hueg, Jr., *Professor of Agronomy* and *Deputy Vice President* and *Dean*, Institute of Agriculture, Forestry, and Home Economics, University of Minnesota, St. Paul, Minnesota.

*Marian E. Koshland, *Professor of Bacteriology and Immunology*, University of California, Berkeley, California.

Joseph M. Pettit, *President*, Georgia Institute of Technology, Atlanta, Georgia.

Alexander Rich, *Sedgwick Professor of Biophysics*, Massachusetts Institute of Technology, Cambridge, Massachusetts.

Terms Expire May 10, 1984

Lewis M. Branscomb, *Vice President* and *Chief Scientist*, International Business Machines, Inc., Armonk, New York.

Eugene H. Cota-Robles, *Professor of Biology*, University of California, Santa Cruz, California.

Ernestine Friedl, *Professor of Anthropology*, Duke University, Durham, North Carolina.

Michael Kasha, *Director*, Institute of Molecular Biophysics and *Professor of Physical Chemistry*, Florida State University, Tallahassee, Florida.

Walter E. Massey, *Director*, Argonne National Laboratory, Argonne, Illinois.

David V. Ragone, *Dean*, College of Engineering, University of Michigan, Ann Arbor, Michigan.

Edwin E. Salpeter, *J. G. White Professor of Physical Sciences*, Cornell University, Ithaca, New York.

Charles P. Slichter, *Professor of Physics*, University of Illinois, Urbana, Illinois.

Member Ex Officio

*Richard C. Atkinson (Chairman, Executive Committee), *Director*, National Science Foundation.

Vernice Anderson, *Executive Secretary*, National Science Board, National Science Foundation.

NATIONAL SCIENCE FOUNDATION STAFF

Director, Richard C. Atkinson
Deputy Director, George C. Pimentel
Director, Equal Employment Opportunity, Herbert Harrington, Jr.
General Counsel, Charles H. Herz
Director (Acting), Office of Government and Public Programs, Thomas Ubois
Deputy Director, Office of Government and Public Programs, Gaylord L. Ellis
  Associate Director for Public Programs, Theodore D. Drury
  Head, Congressional Liaison Branch, Patricia E. Nicely
  Head, Public Information Branch, Jack Renirie
  Head, Communications Resource Branch, Bruce K. Abell
  Head, Community Affairs Branch, R. Lynn Carroll
Director, Office of Planning and Resources Management, M. Kent Wilson
Deputy Director, Office of Planning and Resources Management, Irwin M. Pikus
  Director, Division of Budget and Program Analysis, Syl McNinch, Jr.
  Head, Budget Office, Thomas Ryan
  Head (Acting), Programming Office, Syl McNinch
  Head, Division of Strategic Planning and Analysis, Vacant
  Head, Planning and Policy Analysis Office, Vacant
  Head, Program Review Office, Lewis P. Jones
Director, Office of Audit and Oversight, Jerome H. Fregeau
Deputy Director, Office of Audit and Oversight, Robert B. Boyden
  Head, Audit Office, Robert B. Boyden
  Head, Evaluation Staff, Harry J. Piccariello
Director, Office of Small Business Research and Development, Theodore W. Wirths
Assistant Director for Engineering and Applied Science, Jack T. Sanderson

---

*Member, Executive Committee.

- *Deputy Assistant Director for Engineering and Applied Science,* Henry C. Bourne
- *Director of Operations,* Richard J. Green
    - *Director, Division of Applied Research,* L. Vaughn Blankenship
    - *Director, Division of Problem-Focused Research,* Donald Senich
    - *Director, Division of Intergovernmental Science and Public Technology,* William Wetmore
    - *Director, Division of Electrical, Computer and Systems Engineering,* Yoh-Han Pao
    - *Director, Division of Chemical and Process Engineering,* Marshall M. Lih
    - *Director, Division of Civil and Mechanical Engineering,* Ernest Masur
- *Assistant Director (Acting), for Astronomical, Atmospheric, Earth, and Ocean Sciences,* Albert L. Bridgewater
- *Deputy Assistant Director for Astronomical, Atmospheric, Earth and Ocean Sciences,* Vacant
    - *Director, Division of Earth and Ocean Sciences,* William E. Howard
    - *Director, Division of Atmospheric Sciences,* Alan J. Grobecker
    - *Director, Division of Earth Sciences,* Peter R. Brett
    - *Director, Division of Ocean Sciences,* Dirk Frankenberg
    - *Director, Division of Polar Programs,* Edward P. Todd
- *Assistant Director for Biological, Behavioral, and Social Sciences,* Eloise E. Clark
- *Deputy Assistant Director for Biological, Behavioral, and Social Sciences,* Robert Rabin
    - *Director, Division of Behavioral and Neural Sciences,* Richard T. Loutitt
    - *Director (Acting), Division of Environmental Biology,* John L. Brooks
    - *Director, Division of Physiology, Cellular and Molecular Biology,* James Campbell
    - *Director, Division of Social and Economic Sciences,* Herbert L. Costner
- *Assistant Director for Mathematical, and Physical Sciences,* James A. Krumhansl
- *Deputy Assistant Director for Mathematical and Physical Sciences,* Richard E. Kagarise
    - *Director, Division of Chemistry,* Richard S. Nicholson
    - *Director, Division of Materials Research,* Herbert S. Bennett
    - *Director, Division of Mathematical and Computer Sciences,* John R. Pasta
    - *Director, Division of Physics,* Marcel Bardon
- *Assistant Director for Science Education,* F. James Rutherford
- *Deputy Assistant Director for Science Education,* Walter L. Gillespie
    - *Director, Office of Program Integration,* Alphonse Buccino
    - *Director, Office of Science and Society,* Alexander J. Morin
    - *Director, Division of Science Education Development and Research,* Joseph Lipson
    - *Director, Division of Science Education Resources Improvement,* Marjorie Gardner
    - *Director, Division of Scientific Personnel Improvement,* Lewis A. Gist
- *Assistant Director for Scientific, Technological, and International Affairs,* Harvey Averch
- *Deputy Assistant Director for Scientific, Technological, and International Affairs,* Leonard L. Lederman
- *Director of Operations and Analysis,* Richard R. Ries
- *Director of Strategic Planning and Assessment,* Leonard L. Lederman
    - *Director, Division of International Programs,* Bodo Bartocha
    - *Director, Division of Policy Research and Analysis,* Alden S. Bean
    - *Director, Division of Information Science and Technology,* Howard L. Resnikoff
- *Assistant Director for Administration,* Thomas Ubois
- *Deputy Assistant Director for Administration,* George Pilarinos
    - *Director, Division of Financial and Administrative Management,* Burl Valentine
    - *Director, Division of Grants and Contracts,* Kenneth B. Foster
    - *Director (Acting), Division of Information Systems,* Richard S. Nicholson
    - *Director, Division of Personnel and Management,* Fred K. Murakami
    - *Director, Health Service,* James S. Long, M.D.

ADVISORY COMMITTEES AND PANELS

OFFICE OF THE DIRECTOR

The Alan T. Waterman Award Committee

Terms Expire December 31, 1979

Raoul Bott
Higgins Professor of Mathematics
Harvard University

W. Robert Marshall, Jr.
Dean, College of Engineering
University of Wisconsin, Madison

Marc L. Nerlove
Cook Professor of Economics
Northwestern University

Frederick Seitz
President
Rockefeller University

Terms Expire December 31, 1980

Floyd E. Bloom
Director, Arthur Vining Davis Center for Behavioral Neurobiology
Salk Institute, La Jolla, California

Frank D. Drake
Professor of Astronomy and Director, National Astronomy and Ionosphere Center
Cornell University

J. William Schopf
Professor of Geology
University of California, Los Angeles

John T. Wilson
President
University of Chicago

Terms Expire December 31, 1981

Winifred W. Doane
Professor of Zoology
Arizona State University

Charles L. Drake
Professor of Zoology
Dartmouth College

Willis H. Flygare
Professor of Chemistry
University of Illinois

Peter H. Raven
Director, Missouri Botanical Garden and Engelmann Professor of Biology
Washington University

Ex Officio

Richard C. Atkinson
Director
National Science Foundation

Norman Hackerman
Chairman, National Science Board
National Science Foundation

Philip Handler
President
National Academy of Sciences

Courtland D. Perkins
President
National Academy of Engineering

Advisory Council

Ernest A. Boykins, Jr.
President
Mississippi Valley State University

Lisle C. Carter, Jr.
President
University of the District of Columbia

A. R. Chamberlain
President
Colorado State University

Emilio Q. Daddario
Attorney
Washington, D.C.

Bruce B. Darling (Executive Secretary)
Special Assistant to the Director
National Science Foundation

Saville R. Davis
Special Correspondent
The Christian Science Monitor

Herbert I. Fusfeld
Director of the Center for Science and Technology Policy
Graduate School of Public Administration
New York University

Marshall Gordon
Vice President for University Services
Murray State University

Charles L. Hammer
Professor of Physics
Iowa State University

Martina S. Horner
President
Radcliffe College

Thomas J. Jones, Jr.
Vice President for Research
Massachusetts Institute of Technology

William H. Kruskal
Professor of Statistics
University of Chicago

Donald N. Langenberg (Chairman)
Professor of Physics
Faculty of Arts and Sciences
University of Pennsylvania

M. Cecil Mackey
President
Michigan State University

Thomas F. Malone
Director, Holcomb Research Institute
Butler University

Carleton E. McMullin
City Manager
Little Rock, Arkansas

Roger G. Noll
Chairman, Division of the Humanities and Social Sciences
California Institute of Technology

Joseph E. Rowe
Vice President-Technology
Harris Corporation

Halsey L. Royden
Dean, School of Humanities and Sciences
Stanford University

Gilbert Sanchez
Dean of Research
Eastern New Mexico University

Myriam P. Sarachik
Professor of Physics
City College, City University of New York

Riley O. Schaeffer
Professor of Chemistry
University of Wyoming

Eileen F. Serene
Assistant Professor of Philosophy
Yale University

Harold R. Sims
President
Sims International Limited, and Sims and Associates
North Brunswick, New Jersey

Constance P. Tate
Coordinator of Science
Baltimore City Public School System

President's Committee on the National Medal Of Science

Terms Expire December 31, 1979

James H. Cavanaugh
Allegan Pharmaceuticals
Irvine, California

Helen M. Ranney
Department of Medicine, University Hospital
San Diego, California

Steven Weinberg
Higgins Professor of Physics
Harvard University

James B. Wyngaarden
Department of Medicine
Duke University Medical Center

Terms Expire December 31, 1980

Carl Djerassi
Professor of Chemistry
Stanford University

Calvin C. Moore
Professor of Mathematics
University of California, Berkeley

Dorothy M. Simon
AVCO Corporation
Greenwich, Connecticut

John R. Whinnery
Professor of Electrical Engineering
University of California, Berkeley

Terms Expire December 31, 1981

Mary Lowe Good
Boyd Professor of Materials Science
Louisiana State University

W. Dale Compton
Ford Motor Company
Dearborn, Michigan

Leon Max Lederman
Eugene Higgins Professor of Physics
Columbia University

John B. Slaughter
Academic Vice President and Provost
Washington State University

Ex Officio

Philip Handler
President
National Academy of Sciences

Frank Press
Science and Technology Adviser to the President
Director, Office of Science and Technology Policy

DIRECTORATE FOR ASTRONOMICAL, ATMOSPHERIC, EARTH, AND OCEAN SCIENCES

Advisory Committee for Astronomical Sciences

Sandra M. Faber
Lick Observatory
University of California, Santa Cruz

Robert Gehrz
Department of Physics & Astronomy
University of Wyoming

James Gunn
Robinson Laboratory
California Institute of Technology

Arthur A. Hoag
Lowell Observatory
Flagstaff, Arizona

Richard Huguenin
Department of Physics & Astronomy
University of Massachusetts

Kenneth Kellermann
Max Planck Institut fur Radioastronomie
Bonn, West Germany

Joseph S. Miller
Lick Observatory
University of California, Santa Cruz

Arno Penzias
Radio Research Laboratory
Holmdel, New Jersey

Gordon H. Pettengill
Department of Earth & Planetary Sciences
Massachusetts Institute of Technology

Peter A. Strittmatter (Chairman)
Steward Observatory
University of Arizona

Charles H. Townes
Department of Physics
University of California, Berkeley

Arthur Walker, Jr.
Department of Applied Physics
Stanford University

William D. Watson
Department of Astronomy
University of Illinois, Urbana

Subcommittee on Laboratory and Theoretical Astrophysics

Kenneth Brecher
Department of Physics
Massachusetts Institute of Technology

Alexander Dalgarno
Harvard College Observatory

D. M. Eardley
Physics Department
Yale University

William Fowler
Division of Physics, Math, & Astronomy
California Institute of Technology

D. R. Johnson
National Bureau of Standards
Washington, D.C.

R. A. McCray
JILA
University of Colorado, Boulder

William D. Watson (Chairman)
Department of Physics and Astronomy
University of Illinois, Urbana

Subcommittee on Optical and Infrared Astronomy

Eric E. Becklin
Institute of Astronomy
University of Hawaii

Richard Canfield
Physics Department
University of California, San Diego

Anne P. Cowley
Department of Astronomy
University of Michigan, Ann Arbor

John S. Gallagher
Department of Astronomy
University of Illinois, Urbana

Robert Gehrz (Chairman)
Department of Physics & Astronomy
University of Wyoming

Fred C. Gillett
Kitt Peak National Observatory
Tucson, Arizona

James Gunn
Robinson Laboratory
California Institute of Technology

Joseph S. Miller
Lick Observatory
University of California, Santa Cruz

Edward Ney
School of Physics
University of Minnesota, Minneapolis

Judith L. Pipher
Physics & Astronomy Department
University of Rochester

Harlan J. Smith
Astronomy Department
University of Texas, Austin

Arthur B. Walker
Institute for Plasma Research
Stanford University

Subcommittee on Radio Astronomy

Michael Davis
Arecibo Observatory
Arecibo, Puerto Rico

William Erickson
Astronomy Program
University of Maryland, College Park

Carl B. Heiles
Astronomy Department
University of California, Berkeley

Richard Huguenin (Chairman)
Department of Physics & Astronomy
University of Massachusetts

James Moran
Smithsonian Astrophysical Observatory
Cambridge, Massachusetts

Patrick Palmer
Astronomy & Astrophysics Department
University of Chicago

Paul A. Vanden Bout
Department of Astronomy
University of Texas, Austin

Advisory Committee for Atmospheric Sciences

Donna Blake
National Oceanography Research Development Agency
Bay St. Louis, Mississippi

Reid Bryson
Institute of Environmental Studies
University of Wisconsin, Madison

Stanley A. Changnon
Atmospheric Sciences Section
University of Illinois, Urbana

Paul Crutzen
National Center for Atmospheric Research
Boulder, Colorado

Edwin F. Danielsen
Department of Atmospheric Sciences
Oregon State University

Alexander J. Dessler
Department of Space Physics and Astronomy
Rice University

Harry L. Hamilton
Chairman, Department of Atmospheric Sciences
State University of New York, Albany

Devrie S. Intriligator
Stauffer Hall of Science
University of Southern California, Los Angeles

Cecil E. Leith
National Center for Atmospheric Research
Boulder, Colorado

Gordon J. F. MacDonald (Chairman)
The MITRE Corporation
McLean, Virginia

William McKechney
Bolling Air Force Base
Washington, D.C.

J. Murray Mitchell
National Oceanic and Atmospheric Administration
Silver Spring, Maryland

Andrew F. Nagy
Space Physics Laboratory
University of Michigan, Ann Arbor

Gordon Newkirk
National Center for Atmospheric Research
Boulder, Colorado

Joanne Simpson
Department of Environmental Sciences
University of Virginia

George L. Siscoe
Department of Meteorology
University of California, Los Angeles

John M. Wallace
Department of Atmospheric Sciences
University of Washington, Seattle

Fred White
Arlington, Virginia

Advisory Committee for Earth Sciences
Subcommittee for Geochemistry

William C. Kelly
Department of Geology & Mineralogy
University of Michigan, Ann Arbor

Fred T. MacKenzie
Department of Geological Sciences
Northwestern University

V. Rama Murthy (Chairman)
Department of Geology & Geophysics
University of Minnesota, Minneapolis

Samuel M. Savin
Department of Earth Sciences
Case Western Reserve University

Rosemary Vidale
Los Alamos Scientific Laboratory
Los Alamos, New Mexico

David R. Wones
Department of Geological Sciences
Virginia Polytechnic Institute

Bruce B. Hanshaw (Alternate)
U.S. Geological Survey
Reston, Virginia

Subcommittee for Geology

Claude C. Albritton, Jr.
Department of Geological Sciences
Southern Methodist University

John S. Crowell
Department of Geology
University of California, Santa Barbara

John C. Harms
Denver Research Center
Marathon Oil Company

Allison R. Palmer
Department of Earth & Space Sciences
State University of New York, Stony Brook

Gershon D. Robinson
U.S. Geological Survey
Menlo Park, California

Donald G. McCubbin (Alternate)
Denver Research Center
Marathon Oil Company

Subcommittee for Geophysics

William F. Brace
Department of Earth & Planetary Science
Massachusetts Institute of Technology

Michael D. Fuller
Department of Geological Sciences
University of California, Santa Barbara

Freeman Gilbert
Scripps Institution of Oceanography
University of California, Berkeley

Hiroo Kanamori
Division of Geology & Planetary Science
California Institute of Technology

Advisory Committee for Ocean Sciences
Executive Committee

Wallace Broecker
Lamont-Doherty Geological Observatory
Columbia University

John V. Byrne
School of Oceanography
Oregon State University

Richard C. Dugdale (Chairman)
Bigelow Laboratory of Ocean Sciences
West Boothbay Harbor, Maine

John Imbrie
Department of Geological Sciences
Brown University

Reuben Lasker
National Marine Fisheries Service
Department of Commerce
La Jolla, California

Mary A. McWhinnie
Department of Biological Sciences
DePaul University

Joseph L. Reid
Scripps Institution of Oceanography
University of California, San Diego

Ferris Webster
National Oceanic & Atmospheric Administration
Department of Commerce
Rockville, Maryland

Warren S. Wooster
Institute of Marine Studies
University of Washington, Seattle

Subcommittee for Program Oversight and Evaluation

Wallace Broecker
Lamont-Doherty Geological Observatory
Columbia University

John V. Byrne (Chairman)
School of Oceanography
Oregon State University

Edward Chin
Professor
University of Georgia

David W. Folger
Office of Marine Geology
U.S. Geological Survey
Woods Hole, Massachusetts

David Helpern
Pacific Marine Environmental Laboratory
Seattle, Washington

Dennis E. Hayes
Department of Submarine Topography
Lamont-Doherty Geological Observatory
Columbia University

John Imbrie
Department of Geological Sciences
Brown University

Galen E. Jones
Department of Microbiology
University of New Hampshire

Reuben Lasker
National Marine Fisheries Service
Department of Commerce
La Jolla, California

Christopher S. Marten
Marine Sciences Program
University of North Carolina, Chapel Hill

Mary A. McWhinnie
Department of Biological Sciences
DePaul University

Joseph L. Reid
Professor
University of California, La Jolla

David R. Schink
Department of Oceanography
Texas A&M University

Paul E. Smith
National Marine Fisheries Service
Department of Commerce
La Jolla, California

Robert Smith
School of Oceanography
Oregon State University

Warren Wooster
Institute of Marine Studies
University of Washington, Seattle

Subcommittee for Oceanographic Facilities and Support

John L. Abbott
Scripps Institution of Oceanography
University of California, San Diego

Michael L. Bender
Department of Oceanography
University of Rhode Island

William C. Boicourt
Cheasapeake Bay Institute
John Hopkins University

Emma R. Dieter
Institute of Marine Science
University of Alaska, Seward

Robert D. Gerard
Lamont-Doherty Geological Observatory
Columbia University

Roderick S. Mesecar
Department of Oceanography
Oregon State University

T. K. Treadwell (Chairman)
Department of Oceanography
Texas A&M University

Subcommittee for Ocean Sciences Research

Michael L. Bender
Department of Oceanography
University of Rhode Island

William C. Boicourt
Chesapeake Bay Institute
Johns Hopkins University

Kenneth W. Bruland
Professor
University of California, Santa Cruz

Angelo F. Carlucci
Institute of Marine Resources
University of California, San Diego

Paul J. Fox
Department of Geological Sciences
State University of New York, Albany

Robert B. Gagosian
Department of Chemistry
Woods Hole Oceanographic Institution
Woods Hole, Massachusetts

James V. Gardner
U.S. Geological Survey
Menlo Park, California

Frederick J. Grassle
Woods Hole Oceanographic Institution
Woods Hole, Massachusetts

G. Ross Heath
Graduate School of Oceanography
University of Rhode Island

Edward D. Houde
Rosenstiel School of Marine & Atmospheric Sciences
University of Miami

David C. Hurd
Hawaii Institute of Geophysics
University of Hawaii

Donald M. Hussong
Hawaii Institute of Geophysics
University of Hawaii

Ants Leetmaa
National Oceanic and Atmospheric Administration
Miami, Florida

Victor J. Linnenbom
Office of Naval Research
Washington, D.C.

Christopher N. K. Mooers
Department of Oceanography
U.S. Navy Post Graduate School
Monterey, California

Peter R. Tatro
Science Applications, Inc.
McLean, Virginia

Kenneth L. Webb
Environmental Biology Section
Virginia Institute of Marine Sciences

Advisory Committee for Polar Programs Subcommittee on Glaciology

Wallace Broecker
Department of Geology
Columbia University

Albert P. Crary
Washington, D.C.

Stephen E. Dwornik
Office of Space Sciences & Applications
National Aeronautics & Space Administration

Robert E. Francois
Applied Physics Laboratory
University of Washington

Walter B. Kamb
Division of Geology & Planetary Science
California Institute of Technology

Samuel O. Raymond
Benthos, Inc.
North Falmouth, Massachusetts

Paul V. Sellman
USA/CRREL
Hanover, New Hampshire

Stanley D. Wilson
Seattle, Washington

Subcommittee on Polar Biology and Medicine

Gilbert V. Levin
Biospherics, Incorporated
Rockville, Maryland

Peter Mazur
Biology Division
Oak Ridge National Laboratory

Frank A. Pietelka
Department of Zoology
University of California, Berkeley

Robert L. Rausch
School of Medicine
University of Washington, Seattle

Emanuel D. Rudolph
Professor of Botany
Ohio State University, Columbus

John H. Ryther
Woods Hole Oceanographic Institution
Woods Hole, Massachusetts

Howard H. Seliger
Department of Biology
Johns Hopkins University

William L. Sladen
School of Hygiene and Public Health
Johns Hopkins University

Lee M. Talbot
Council on Environmental Quality
McLean, Virginia

Clayton M. White
Department of Zoology
Brigham Young University

DIRECTORATE FOR BIOLOGICAL, BEHAVIORAL, AND SOCIAL SCIENCES

Advisory Committee for Behavioral and Neural Sciences

Subcommittee for Psychobiology

Elizabeth K. Adkins
Department of Psychology
Cornell University

Elliott M. Blass
Psychology Department
The Johns Hopkins University

Jack W. Bradbury
Department of Biology
University of California, San Diego

F. Robert Brush
Experimental Psychology Laboratory
Syracuse University

Gordon M. Burghardt
Department of Psychology
University of Tennessee, Knoxville

J. Bruce Overmier
Department of Psychology
University of Minnesota, Minneapolis

Gene P. Sackett
Regional Primate Research Center
University of Washington

Barry Schwartz
Department of Psychology
Swarthmore College

Subcommittee for Physical Anthropology and Archaeology

C. Melvin Aikens
Department of Anthropology
University of Oregon

George J. Armelagos
Department of Anthropology
University of Massachusetts, Amherst

Alan E. Mann
Department of Anthropology
University of Pennsylvania

Anthony E. Marks
Department of Anthropology
Southern Methodist University

Charles L. Redman
Department of Anthropology
State University of New York, Binghamton

William Sanders
Department of Anthropology
Pennsylvania State University,
University Park

R. Ervin Taylor
Department of Anthropology
University of California, Riverside

Subcommittee for Cultural-Social Anthropology

Jane Collier
Department of Anthropology
Stanford University

May M. Ebihara
New York, New York

Hildred Geertz
Department of Anthropology
Princeton University

Michael Kenny
Department of Anthropology
Catholic University of America

John U. Ogbu
Department of Anthropology
University of Connecticut

Carol A. Smith
Department of Anthropology
Duke University

Subcommittee for Anthropological Collections

William W. Fritzhugh
Department of Anthropology
Smithsonian Institution

Richard Ford
Sante Fe, New Mexico

Bill Holm
T. Burke Memorial Washington State
Museum
University of Washington

Delores Newton
Department of Anthropology
State University of New York, Stony Brook

Joe Ben Wheat
University Museum
University of Colorado, Boulder

Subcommittee for Linguistics

Stephen R. Anderson
Department of Linguistics
University of California, Los Angeles

James E. Deese
Department of Psychology
University of Virginia

Catherine J. Garvey
Department of Psychology
Johns Hopkins University

Chin-Wu Kim
Department of Linguistics
University of Illinois

Edith A. Moravcsik
Department of Linguistics
University of Wisconsin, Milwaukee

Albert Valdman
Department of Linguistics
Indiana University, Bloomington

Subcommittee for Neurobiology

Michael Brownstein
National Institutes of Health
Bethesda, Maryland

Judith A. Finkelstein
College of Medicine
Northeastern Ohio Universities

Russell G. Durkovic
Department of Physiology
Upstate Medical Center
Syracuse, New York

Rodger O. Eckert
Department of Biology
University of California, Los Angeles

R. Kevin Hunt
Department of Biophysics
Johns Hopkins University

Christiana M. Leonard
Department of Neuroscience
University of Florida

Henry G. Nautner
Department of Biochemistry and Pharmacology
Tufts University

Donald E. McMillan
Department of Pharmacology
University of Arkansas Medical Sciences

Rodney K. Murphey
Department of Biology
State University of New York, Albany

M. Ian Phillips
Department of Physiology and Biophysics
University of Iowa

Lynda L. Uphouse
Departmnt of Psychology
Yale University

Y. Peng Loh
Laboratory of Developmental Neurobiology
National Institute of Child Health and Human Development
Bethesda, Maryland

William L. R. Cruce
College of Medicine
Northeastern Ohio Universities

Subcommittee for Sensory Physiology and Perception

John F. Brugge
Department of Neurophysiology
University of Wisconsin, Madison

Ann M. Graybiel
Department of Psychology
Massachusetts Institute of Technology

Bruce P. Halpern
Department of Psychology
Cornell University

Herbert P. Killackey
Department of Psychology
University of California, Irvine

Herschel W. Leibowitz
Evan Pugh Professor of Psychology
University of Pennsylvania, University Park

Walter Makous
Center for Visual Sciences
University of Rochester

Frank L. Margolis
Department of Physiology Chemistry
Rochester Institute of Molecular Biology

Conrad G. Mueller
Center for Neural Sciences
Indiana University

David C. Van Essen
Division of Biology
California Institute of Technology

Charles S. Watson
Director of Research
Boys Town Institute for Communication Disorders in Children
Omaha, Nebraska

Subcommittee of Memory and Cognitive Processes

Lynn A. Cooper
Department of Psychology
Cornell University

Walter Kintsch
Department of Psychology
University of Colorado, Boulder

Jean Mandler
Department of Psychology
University of California, San Diego

Richard B. Millward
Department of Psychology
Brown University

Gary Olson
Department of Psychology
University of Michigan, Ann Arbor

Mary C. Potter
Department of Psychology
Massachusetts Institute of Technology

Subcommittee for Social and Developmental Psychology

W. Andrew Collins
Institute for Child Development
University of Minnesota, Minneapolis

William D. Crano
Department of Psychology
Michigan State University, East Lansing

Reid Hastie
Department of Psychology and Social Relations
Harvard University

Robert W. Krauss
Department of Psychology
Columbia University

Hazel Markus
Institute for Social Research
University of Michigan, Ann Arbor

Philip R. Zelazo
Department of Pediatrics
Tufts New England Medical Center
Boston, Massachusetts

Advisory Committee for Environmental Biology
Subcommittee for Systematic Biology

William R. Atchley
Department of Entomology
University of Wisconsin, Madison

Alan H. Brush
Associate Professor
University of Connecticut

Guy Bush
Department of Zoology
University of Texas, Austin

Daniel Crawford
Department of Botany
Ohio State University, Columbus

David L. Dilcher
Department of Botany
Indiana University

David E. Fairbrothers
Department of Botany
Rutgers University

Melvin S. Fuller
Department of Botany
University of Georgia

Leslie D. Gottlieb
Department of Genetics
University of California, Davis

Stephen J. Gould
Museum of Comparative Zoology
Harvard University

Arnold G. Kluge
Curator, Department of Zoology
University of Michigan, Ann Arbor

Willard W. Payne
Director Cary Aboretum
New York Botanical Garden

Leonard Radinsky
Department of Anatomy
University of Chicago

Subcommittee for Ecological Sciences

John D. Allan
Department of Zoology
University of Maryland

Daniel B. Botkin
Woodrow Wilson International Center for Scholars
Smithsonian Institution

Rex G. Cates
Department of Biology
University of New Mexico

Margaret B. Davis
Department of Ecology
University of Minnesota, Minneapolis

Gordon W. Frankie
Department of Entomology
University of California, Berkeley

William M. Lewis, Jr.
Department of EPO Biology
University of Colorado, Boulder

James A. MacMahon
Department of Biology
Utah State University

Robert V. O'Neill
Ecological Sciences Division
Oak Ridge National Laboratory

James R. Sedell
Weyerhaeuser Corporation
Centralia, Washington

Richard H. Waring
Forest Resources Laboratory
Oregon State University

William J. Wiebe
Department of Microbiology
University of Georgia

Larry L. Wolf
Department of Zoology
Syracuse University

Subcommittee for Population and Physiological Ecology

Wyatt W. Anderson
Department of Zoology
University of Georgia

Brian F. Chabot
Department of Biological Sciences
Cornell University

Michael T. Clegg
Department of Botany
University of Georgia

Jerry F. Downhower
Department of Zoology
Ohio State University, Columbus

Nelson G. Hariston
Department of Zoology
University of North Carolina, Chapel Hill

Richard K. Koehn
Department of Ecology & Evolution
State University of New York, Stony Brook

Donald A. Levin
Department of Botany
University of Texas, Austin

Richard E. MacMillen
Department of Ecology & Evolutionary Biology
University of California, Irvine

Charlotte Mangum
Department of Zoology
College of William & Mary

Jeffrey B. Mitton
Department of EPO Biology
University of Colorado, Boulder

Peter W. Price
Department of Entomology
University of Illinois, Urbana

Daniel S. Simberloff
Department of Biological Science
Florida State University

Henry E. Schaffer
Department of Genetics
North Carolina State University

Robert C. Vrijenhoek
Department of Zoology
Rutgers University

Advisory Committee for Physiology, Cellular, and Molecular Biology
Executive Subcommittee of the Advisory Committee for Physiology, Cellular, and Molecular Biology

Sherwood Casjens
Department of Cellular and Molecular Biology
University of Utah

Stanley Gartler
Department of Genetic Biology
University of Washington, Seattle

Peter Hepler
Department of Botany
University of Massachusetts

R. Bruce Nicklas
Department of Zoology
Duke University

Advisory Committee on Developmental Biology

Susan Bryant
Center for Pathobiology
University of California, Irvine

Verne M. Chapman
Department of Molecular Biology
Roswell Park Memorial Institute

Elizabeth D. Earle
Department of Plant Breeding
Cornell University

Charles Emerson
Department of Biology
University of Virginia

John Fallon
Department of Anatomy
University of Wisconsin, Madison

Anne Fausto-Sterling
Department of Biology & Medical Science
Brown University

Nina V. Fedoroff
Department of Embryology
Carnegie-Institution of Washington
Baltimore, Maryland

Joseph Frankel
Department of Zoology
University of Iowa

L. Patrick Gage
Department of Cell Biology
Roche Institute of Molecular Biology

Mildred Gordon
Center for Biomedical Education
City College of City University
New York, New York

George M. Malacinski
Department of Zoology
Indiana University

Roger Pedersen
Laboratory of Radio Biology
University of California, San Francisco

Ralph Quatrano
Department of Botany & Plant Pathology
Oregon State University

Jean-Paul Revel
Divison of Biology
California Institute of Technology

Larry N. Vanderhoef
Department of Botany
University of Illinois, Urbana

C. Peter Wolk
Plant Research Laboratory
Michigan State University, East Lansing

Subcommittee for Genetic Biology

Elias Balbinder
Director of Genetics
American Cancer Center and Hospital
Lake Wood, Colorado

Ann K. Ganesan
Department of Biology
Stanford University

Susan Gerbi
Department of Biology
Brown University

Warren Jelinek
Department of Molecular Cellular Biology
Rockefeller University

Roy A. Jensen
Department of Biological Sciences
State University of New York, Binghamton

Margaret Lieb
Department of Microbiology
University of Southern California

Richard Losick
Biological Laboratories
Harvard University

Paul S. Lovett
Department of Bio Sciences
University of Maryland, Baltimore

Paul T. Magee
Department of Microbiology &
Public Health
Michigan State University, East Lansing

George A. Marzluf
Department of Biochemistry
Ohio State University, Columbus

Neil H. Mendelson
Department of Microbiology & Medical
Technology
University of Arizona, Tucson

Peter Palese
Department of Microbiology
Mt. Sinai School of Medicine

William Reznikoff
Department of Biology
University of Wisconsin, Madison

Marcus M. Rhoades, Jr.
Department of Biology
Johns Hopkins University

Immo Scheffler
Department of Biology
University of California, San Diego

James F. Shepard
Department of Plant Pathology
University of California, Davis

William C. Summers
Department of Molecular Biophysics
and Biochemistry
Yale University

Rudolf Werner
Department of Biochemistry
University of Miami

Reed B. Wickner
Laboratory of Biochemistry, Pharmacology
National Institutes of Health
Bethesda, Maryland

Subcommittee for Cell Biology

David Fred Albertini
Department of Anatomy
Harvard Medical School

Eilezer Benjamini
Department of Medical Microbiology
University of California, Davis

Robert Scott Decker
Department of Cell Biology
University of Texas

Daniel L. Friedman
Department of Molecular Biology
Vanderbilt University

Susan Joyce Friedman
Department of Pharmacology
University of Colorado Medical Center

Paul B. Green
Department of Biology
Stanford University

Carol Heckman
Biology Division
Oak Ridge National Laboratory

Warren R. Jelinek
Department of Molecular and Cell Biology
Rockefeller University

Judith A. Kapp
Department of Pathology
Washington University Medical Center

Oscar Lee Miller, Jr.
Department of Biology
University of Virginia

John Richard McIntosh
Department of Molecular, Cellular, and
Developmental Biology
University of Colorado, Boulder

Richard E. Pagano
Department of Embryology
Carnegie Institution of Washington
Baltimore, Maryland

Gordhan L. Patel
Department of Zoology
University of Georgia

Paula M. Pitha
Biochemical Virology Laboratory
Johns Hopkins University Oncology Center

Robert W. Rubin
Department of Anatomy
University of Miami School of Medicine

Nancy H. Ruddle
Department of Epidemiology
Yale University Medical School

Peter J. Stambrook
Department of Biology
Case Western Reserve University

Robert Taber
Department of Viral Oncology
Roswell Park Memorial Institute

Carol M. Warner
Department of Biochemistry & Biophysics
Iowa State University of Sciences
& Technology

Richard C. Weisenberg
Department of Biology
Temple University

Christopher L. Woodcock
Department of Zoology
University of Massachusetts

James H. Wyche
Department of Biochemistry
University of Missouri, Columbia

Subcommittee for Molecular Biology (Panel A)

Rodney L. Biltonen
Department of Biochemistry
University of Virginia

Marshall Elzinga
Department of Biology
Brookhaven National Laboratory

Guido Guidotti
Biological Laboratories
Harvard University

George P. Hess
Section of Biochemistry & Molecular Biology
Cornell University

Lawrence Kahan
Department of Physiological Chemistry
University of Wisconsin, Madison

John Lenard
Department of Physiology
Rutgers University Medical School

Alan N. Schechter
Laboratory of Chemical Biology
National Institute of Arthritis Metabolism and Digestive Diseases
National Institutes of Health

Frederick I. Tsuji
Department of Biological Sciences
University of Southern California

Subcommittee for Molecular Biology (Panel B)

Sherman Beychok
Department of Biological Sciences
Columbia University

William A. Cramer
Department of Biological Sciences
Purdue University

Donald Crothers
Department of Chemistry
Yale University

John W. B. Hershey
Department of Biological Chemistry
University of California, Davis

Claude B. Klee
Laboratory for Biochemistry
National Cancer Institute
National Institutes of Health

David W. Krogmann
Department of Biochemistry
Purdue University

Irwin D. Kuntz
Department of Pharmaceutical Chemistry
University of California, San Francisco

Karl H. Muench
Department of Medicine
University of Miami

Milton J. Schlesinger
Department of Microbiology
Washington University

Paul Sigler
Department of Biophysics and Theoretical Biology
Cummings Life Science Center

George R. Stark
Department of Biochemistry
Stanford University

Christopher T. Walsh
Department of Chemistry
Massachusetts Institute of Technology

Reed B. Wickner
National Institute of Arthritis, Metabolic, and Digestive Diseases
National Institutes of Health

Eckard Wimmer
School of Basic Health Science
State University of New York, Stony Brook

Subcommittee for Human Cell Biology

Philip Coffino
Department of Microbiology
University of California, San Francisco

Paul Gottlieb
Center for Cancer Research
Massachusetts Institute of Technology

Terry Grodzicker
Cold Spring Harbor Laboratory
Cold Spring Harbor, New York

Gregory Milman
Department of Biochemistry
Johns Hopkins University

Milton Schlesinger
Department of Microbiology
Washington University

David C. Tiemeier
Department of Biological Chemistry
University of California, Irvine

Subcommittee on Regulatory Biology

Ronald H. Alvarado
Department of Zoology
Arizona State University

Peter J. Bentley
Department of Pharmacology
Mount Sinai School of Medicine
City University of New York

Stephen H. Bishop
Department of Zoology
Iowa State University

Susan W. Farmer
Hormone Research Laboratory
University of California, San Francisco

Thomas O. Fox
Department of Neuroscience
Children's Hospital Medical Center
Boston, Massachusetts

Wendell W. Leavitt
Worcester Foundation for Experimental Biology
Shrewsbury, Massachusetts

James W. Putney, Jr.
Department of Zoology and Entomology
Wayne State University School of Medicine

Charles L. Ralph
Department of Zoology and Entomology
Colorado State University, Fort Collins

Judith A. Ramaley
Department of Physiology and Biophysics
University of Nebraska Medical Center

John L. Roberts
Department of Zoology
University of Massachusetts, Amherst

Marion J. Siegman
Department of Physiology
Thomas Jefferson University

Walter R. Tschinkel
Department of Biological Science
Florida State University

Subcommittee for Metabolic Biology

Louise E. Anderson
Department of Biological Sciences
University of Illinois, Chicago

James A. Bassham
Lawrence Berkeley Laboratory
University of California, Berkeley

Jean E. Brenchley
Department of Biological Sciences
Purdue University

Deborah Delmer
MSU/ERDA Plant Research Laboratory
Michigan State University, East Lansing

Lowell P. Hager
Department of Biochemistry
University of Illinois, Urbana

Mary Ellen Jones
Department of Biochemistry & Nutrition
University of North Carolina, Chapel Hill

Henry Kamin
Department of Biochemistry
Duke University

Evangelos N. Moudrianakis
Department of Biology
Johns Hopkins University

Barry P. Rosen
Department of Biological Chemistry
University of Maryland, Baltimore

George Sachs
Department of Medicine
University of Alabama

Advisory Committee for Social and Economic Sciences
Subcommittee for Economics

Robert J. Barro
Department of Economics
University of Rochester

Michael J. Boskin
Department of Economics
Stanford University

Gregory C. Chow
Department of Economics
Princeton University

Stanley Fischer
Department of Economics
Massachusetts Institute of Technology

Arthur S. Goldberger
Department of Economics
University of Wisconsin, Madison

James H. Heckman
National Bureau of Economic Research
Palo Alto, California

John O. Ledyard
Center for Mathematical Studies
Northwestern University

Stephen P. Magee
Department of Finance
University of Texas, Austin

Andreu Mas-Collel
Department of Economics
University of California, Berkeley

A. Michael Spence
Department of Economics
Harvard University

Gavin Wright
Department of Economics
University of Michigan, Ann Arbor

Subcommittee for Geography and Regional Science

K. Patricia Burnett
Department of Geography
Northwestern University

Melvin G. Marcus
Department of Geography
Arizona State University, Tempe

Marvin W. Mikesell
Department of Geography
University of Chicago

Gerard Rushton
Department of Geography
University of Iowa

Daniel R. Vining, Jr.
Regional Science Department
University of Pennsylvania

Julian Wolpert
School of Architecture & Urban Planning
Princeton University

Subcommittee for History and Philosophy of Science

Arthur W. Burks
Department of Computer and Communications Sciences
University of Michigan, Ann Arbor

Ruth Cowan
Department of History
State University of New York, Stony Brook

Arthur Donovan
Department of History
West Virginia University

John Heilbron
Office for History of Science and Technology
University of California, Berkeley

Dorothy Ross
Department of History
University of Virginia

Merrilee Salmon
Department of Philosophy
University of Arizona, Tucson

Howard Stein
Department of History
Columbia University

Linda Wessels
Department of History and Philosophy of Science
Indiana University

Subcommittee for Law and Social Sciences

Shari Diamond
Department of Criminal Justice
University of Illinois, Chicago

John P. Heinz
School of Law
Northwestern University

Richard O. Lempert
Law School
University of Michigan, Ann Arbor

Richard S. Markovits
Law School
University of Texas, Austin

Robert Seidman
School of Law
Boston University

Barbara Yngvesson
Department of Anthropology
Hampshire College

Subcommittee for Political Science

Joel D. Aberbach
The Brookings Institution
Washington, D.C.

Charles W. Anderson
Department of Political Science
University of Wisconsin, Madison

Robert E. Erikson
Department of Political Science
University of Houston

John A. Ferejohn
Division of Humanities and Social Sciences
California Institute of Technology

William R. Keech
Department of Political Science
University of North Carolina, Chapel Hill

Robert O. Keohane
Department of Political Science
Stanford University

Sidney Tarrow
Department of Political Science
Cornell University

Susan Welch
Department of Political Science
University of Nebraska

Subcommittee for Sociology

Karen Cook
Department of Sociology
University of Washington, Seattle

Joan A. Huber
Department of Sociology
University of Illinois, Urbana

Stanley Lieberson
Department of Sociology
University of Arizona, Tucson

Anne M. McMahon
Department of Sociology
University of Rochester

Nicholas C. Mullins
Department of Sociology
Indiana University

Peter H. Rossi
Department of Sociology
University of Massachusetts

Herman Turk
Department of Sociology and Anthropology
University of Southern California

James J. Zuiches
Department of Sociology
Michigan State University, East Lansing

DIRECTORATE FOR ENGINEERING APPLICATIONS AND APPLIED SCIENCE

Advisory Committee for Applied Science and Research Applications Policy

David M. Bartley
Holyoke Community College
Holyoke, Massachusetts

Robert R. Berks
Orient, New York

John A. Blume
URS/John A. Blume & Associates, Engineers
San Francisco, California

Frank C. DiLuzio
Government & University Relations
Los Alamos Scientific Research Laboratory
Los Alamos, New Mexico

Lewis O. Grant
Department of Atmospheric Sciences
Colorado State University

Thomas F. Jones (Chairman)
Vice President for Research
Massachusetts Institute of Technology

Arthur R. Kantrowitz
AVCO-Everett Research Laboratory
Everett, Massachusetts

Joseph Ling
Environmental Engineering and Pollution Control
3-M Company
St. Paul, Minnesota

Richard P. Nalesnik
Resources and Technology Department
National Association of Manufacturers
Washington, D.C.

Howard Odum
Graduate Research Professor
Environmental Science
University of Florida

Irene C. Peden
Department of Electrical Engineering
University of Washington, Seattle

Howard J. Taubenfeld
Professor of Law
Southern Methodist University

Richard E. Thomas
Zachry Engineering Center
Texas A&M University

Bruce Thrasher
United Steel Workers of America
Pittsburgh, Pennsylvania

William Vogely
Professor of Minneral Economics
Pennsylvania State University,
University Park

Eugene J. Webb
Graduate School of Business
Stanford University

Sylvan Wittwer
Director, Agricultural Experiment Station and Assistant Dean, College of Agriculture and Natural Resources
Michigan State University

Robert B. Yegge
Yegge, Hall & Evans
Denver, Colorado

Roy A. Young
Chancellor
University of Nebraska
Lincoln, Nebraska

Eugene Younts
Vice President for Services
University of Georgia

Subcommittee for Integrated Basic Research

J. David Allan
Department of Zoology
University of Maryland, College Park

Jonathan P. Brezin
Department of Mathematics
University of North Carolina, Chapel Hill

Reid A. Bryson
Institute for Environmental Studies
University of Wisconsin, Madison

Orville L. Chapman
Department of Chemistry
University of California, Los Angeles

Albert P. Crary
Washington, D.C.

Richard C. Dugdale
Bigelow Laboratory of Ocean Sciences
West Boothbay Harbor, Maine

Bruno Giletti
Department of Geological Sciences
Brown University

Cynthia C. Irwin-Williams
Department of Anthropology
Eastern New Mexico University

David W. Krogmann
Department of Biochemistry
Purdue University

David J. Kuck
Department of Computer Science
University of Illinois, Urbana

Walter Makous
Department of Psychology
University of Washington, Seattle

Arthur B. Metzner
Department of Chemical Engineering
University of Delaware

Dale F. Stein
Vice President for Academic Affairs
Michigan Technological University

Walter R. Tschinkel
Biological Sciences
Florida State University

Daniel R. Vining, Jr.
Department of Regional Science
University of Pennsylvania

Arthur B. Walker, Jr.
Institute for Plasma Research
Stanford University

Chia-Wei Woo
Department of Physics & Astronomy
Northwestern University

Roy Young (Chairman)
Chancellor
University of Nebraska
Lincoln, Nebraska

Advisory Committee for Engineering
Subcommittee for Engineering Chemistry and Energetics

David M. Benenson
Department of Electrical Engineering
State University of New York, Buffalo

Edward L. Cussler (Chairman)
Department of Chemical Engineering
Carnegie-Mellon University

James R. Fair, Jr.
Director of Engineering
Monsanto Company
St. Louis, Missouri

Douglas W. Fuerstenau
Department of Materials Science and Engineering
University of California, Berkeley

Robert L. Long
Manager, Generation Productivity
GPU Service Corporation
Parsippany, New Jersey

William D. Maxon
Manager, Fermentation Research and Development
The Upjohn Company

John R. O'Connell
Department of Chemical Engineering
University of Florida

W. Harmon Ray
Department of Chemical Engineering
University of Wisconsin

Darsh T. Wasan
Department of Chemical Engineering
Illinois Institute of Technology

Subcommittee for Mechanical Sciences and Engineering

Samuel B. Batdorf
Aerospace Corporation
El Segundo, California

James W. Dally
School of Engineering
University of Rhode Island

James G. Knudsen
School of Engineering
Oregon State University

Richard L. Peskin
Department of Mechanical Engineering and Aerospace
Rutgers University

Chang-Lin Tien
Department of Mechanical Engineering
University of California, Berkeley

Kyriakos C. Valanis
College of Engineering
University of Cincinnati

Kwang-Tzu Yang (Chairman)
Department of Aerospace and Mechanical Engineering
University of Notre Dame

Subcommittee for Civil and Environmental Engineering

Melvin Baron
Partner and Director of Research
Paul Weidlinger Consulting Engineers
New York, New York

Steven J. Fenves
Department of Civil Engineering
Carnegie-Mellon University

Donald R. F. Harleman
Department of Civil Engineering
Massachusetts Institute of Technology

Ray B. Krone
Department of Civil Engineering
University of California, Davis

James K. Mitchell
Department of Civil Engineering
University of California, Berkeley

George F. Pinder
Department of Civil Engineering
Princeton University

Subcommittee for Electrical Sciences and Analysis

Jonathan Allen
Department of Electrical Engineering
Massachusetts Institute of Technology

Esther M. Conwell
Xerox Corporation
Webster, New York

Samuel Dwyer
Department of Radiology
University of Kansas Medical Center

Hideya Gamo
Department of Electrical Engineering
University of California, Irvine

Petar Kokotovic
Department of Electrical Engineering
University of Illinois, Urbana

Robert J. Mattauch
Department of Electrical Engineering
University of Virginia

James H. Mulligan, Jr.
School of Engineering
University of California, Irvine

George Nemhauser
School of Operations Research and Industrial Engineering
Cornell University

Demetrius T. Paris (Chairman)
School of Electrical Engineering
Georgia Institute of Technology

John Thomas
Department of Electrical Engineering and Computer Science
Princeton University

Bernard Widrow
Department of Electrical Engineering
Stanford University

DIRECTORATE FOR MATHEMATICAL AND PHYSICAL SCIENCES

Advisory Committee for Chemistry

Bruce J. Berne (Chairman)
Department of Chemistry
Columbia University

Orville L. Chapman
Department of Chemistry
University of California, Los Angeles

Dennis H. Evans
Department of Chemistry
University of Wisconsin, Madison

Paul G. Gassman
Department of Chemistry
University of Minnesota

Kendall N. Houk
Department of Chemistry
Louisiana State University

Frederick Kaufman
Department of Chemistry
University of Pittsburgh

Rudolph A. Marcus
Department of Chemistry
California Institute of Technology

George W. Parshall
Central Research & Development Department
E. I. duPont de Nemours & Company
Wilmington, Delaware

Richard R. Schrock
Department of Chemistry
Massachusetts Institute of Technology

David A. Shirley
Department of Chemistry
University of California, Berkeley

Jeanne M. Shreeve
Department of Chemistry
University of Idaho

James D. Winefordner
Department of Chemistry
University of Florida

Albert C. Yates
Department of Chemistry
University of Cincinnati

Advisory Committee for Materials Research

John S. Blakemore
Oregon Graduate Center
Beaverton, Oregon

William Brinkman
Bell Telephone Laboratories
Murray Hill, New Jersey

LeRoy Eyring
Department of Chemistry
Arizona State University

Michael E. Fisher
Baker Laboratory
Cornell University

Robert E. Hansen
Ames Laboratory
Iowa State University

William D. Nix
Department of Materials Science
and Engineering
Stanford University

Charles G. Overgerger
Vice President for Research
University of Michigan

Walter S. Owen
Department of Materials Science and
Engineering
Massachusetts Institute of Technology

John T. Ransom
Experimental Station
E. I. duPont de Nemours & Co.
Wilmington, Delaware

Dale F. Stein
Vice President of Academic Affairs
Michigan Technological University

John B. Wachtman, Jr.
Center for Materials Science
National Bureau of Standards
Washington, D.C.

Subcommittee for Metallurgy and Materials

Raymond F. Decker
INCO Inc.
New York, New York

K. Lawrence DeVries
Department of Mechanical Industrial
Engineering
University of Utah

George E. Dieter
College of Engineering
University of Maryland, College Park

Herbert Morawetz
Department of Chemistry
Polytechnic Institute of New York

William D. Nix
Department of Materials Science and
Engineering
Stanford University

Charles G. Overberger
Vice President for Research
University of Michigan

Walter S. Owen
Department of Materials Science and
Engineering
Massachusetts Institute of Technology

Vivian T. Stannett
Graduate School
North Carolina State University

Robert J. Stokes
Materials Science Center
Honeywell, Inc.
Bloomington, Minnesota

Donald O. Thompson
Rockwell International Science Center
Thousand Oaks, California

Robert W. Vest
School of Materials Engineering
Purdue University

John B. Wachtman, Jr.
Center for Materials Science
National Bureau of Standards
Washington, D.C.

Subcommittee for Condensed Matter Science

William Brinkman
Bell Telephone Laboratories
Murray Hill, New Jersey

J. Gregory Dash
Department of Physics
University of Washington

Dean E. Eastman
Watson Research Center, IBM
Yorktown Heights, New York

Craig J. Eckhardt
Department of Chemistry
University of Nebraska

LeRoy Eyring
Department of Chemistry
Arizona State University

Michael E. Fisher
Baker Laboratory
Cornell University

Hellmut Fritzche
James Franklin Institute
University of Chicago

James D. Litster
Department of Physics
Massachusetts Institute of Technology

Alexei A. Marududin
Department of Physics
University of California, Irvine

Stephen E. Schnatterly
Department of Physics
University of Virginia

William S. Sibley
Department of Physics
Oklahoma State University

Mary Beth Stearns
Ford Research Laboratory
Ford Motor Company

Subcommittee on the Materials Research Laboratories

John S. Blakemore
Oregon Graduate Center
Beaverton, Oregon

K. Lawrence DeVries
Department of Mechanical Engineering
University of Utah

Dean E. Eastman
T. J. Watson Research Center
International Business Machines

Craig J. Eckhardt
Department of Chemistry
University of Nebraska

Ivar Giaever
General Electric Company
Schenectady, New York

Robert S. Hansen
Ames Laboratory
Iowa State University

Alexei A. Maradudin
Department of Physics
University of California, Irvine

John T. Ransom
Experimental Station
E. I. duPont de Nemours & Co.
Wilmington, Delaware

Dale F. Stein
Vice President of Academic Affairs
Michigan Technological University

Robert J. Stokes
Honeywell Corporate Research Center
Bloomington, Minnesota

Donald O. Thompson
Rockwell International
Thousand Oaks, Calfornia

Subcommittee on National Magnet Laboratory

Keith Boyer
Los Alamos Scientific Laboratory
Los Alamos, New Mexico

Simeon A. Friedberg
Department of Physics
Carnegie-Mellon University

Donald M. Ginsberg
Department of Physics
University of Illinois

John J. Hopfield
Department of Physics
Princeton University

Bruce D. McCombe
Naval Research Laboratory
Washington, D.C.

Clyde E. Taylor
Lawrence Livermore Laboratory
University of California, Berkeley

Advisory Committee for Mathematical and Physical Sciences
Subcommittee for Computer Science

Daniel E. Atkins, III
Electrical and Computer Engineering
Department
University of Michigan

Alan P. Batson
Department of Computer Science
University of Virginia

Woodrow W. Bledsoe
Department of Computer Science
University of Texas, Austin

Taylor L. Booth
Department of Electrical Engineering
and Computer Science
University of Connecticut

Edward A. Feigenbaum
Computer Science Department
Stanford University

Albert L. Hopkins, Jr.
C. S. Draper Laboratory
Cambridge, Massachusetts

Barbara H. Liskov
Department of Electrical Engineering
and Computer Science
Massachusetts Institute of Technology

Jack Minker
Department of Computer Science
University of Maryland, College Park

Susan H. Nycum
Portola Valley, California

John Staudhammer
Department of Electrical Engineering
North Carolina State University

Robert W. Taylor
Xerox Corporation
Palo Alto, California

Joseph F. Traub
Computer Science Department
Columbia University

Paul R. Young
Department of Computer Science
Purdue University

Subcommittee for Mathematical Sciences

Jonathan P. Brezin
Department of Mathematics
University of North Carolina

David Eisenbud
Department of Mathematics
Brandeis University

Herbert B. Keller
Department of Applied Mathematics
California Institute of Technology

John Milnor
School of Mathematics
Institute for Advanced Study
Princeton, New Jersey

Ronald Pyke
Department of Mathematics
University of Washington

Paul J. Sally, Jr.
Department of Mathematics
University of Chicago

Frank L. Spitzer
Department of Mathematics
Cornell University

James D. Stasheff
Department of Mathematics
University of North Carolina

W. Gilbert Strang
Department of Mathematics
Massachusetts Institute of Technology

Karen Uhlenbeck
Department of Mathematics
University of Illinois, Chicago

Advisory Committee for Physics

Peter A. Carruthers (Chairman)
Los Alamos Scientific Laboratory
Los Alamos, New Mexico

Wilfried W. Daehnick
Department of Physics
University of Pittsburgh

James E. Faller
Joint Institute for Laboratory Astrophysics
University of Colorado, Boulder

Val L. Fitch
Department of Physics
Princeton University

Hans E. Frauenfelder
Professor
University of Illinois, Urbana

Edward A. Frieman
Plasma Physics Laboratory
Princeton University

Gerson Goldhaber
Department of Physics
University of California, Berkeley

Ernest M. Henley
Department of Physics
University of Washington

Anne Kernan
Department of Physics
University of California, Riverside

Neal F. Lane
Department of Physics
Rice University

Clair E. Max
Lawrence Livermore Laboratory
Livermore, California

Homer Neal
Department of Physics
Indiana University

William H. Press
Harvard College Observatory
Cambridge, Massachusetts

Robert G. Stokstad
Oak Ridge National Laboratory
Oak Ridge, Tennessee

George M. Temmer
Department of Physics
Rutgers University

Chia-Wei Woo
Department of Physics and Astronomy
Northwestern University

C. N. Yang
Institute for Theoretical Physics
State University of New York, Stony Brook

Subcommittee for the Review of Nuclear Science

Barry C. Barish
Division of Physics and Astronomy
California Institute of Technology

William Bertozzi
Department of Physics
Massachusetts Institute of Technology

Wilfried W. Daehnick
Department of Physics
University of Pittsburgh

Robert A. Eisenstein
Associate Professor
Carnegie-Mellon University

Stanley S. Hanna
Professor
Stanford University

Ernest M. Henley
Department of Physics
University of Washington

Neal F. Lane
Department of Physics
Rice University

Robert G. Stokstad
Oak Ridge National Laboratory
Oak Ridge, Tennessee

Georges M. Temmer
Department of Physics
Rutgers University

Subcommittee for the Review of Gravitational Physics

James E. Faller
Joint Institute for Laboratory Astrophysics
University of Colorado, Boulder

Robert P. Geroch
Department of Physics
University of Chicago

James B. Hartle
Department of Physics
University of Chicago

William H. Press
Professor
Harvard College Observatory

Rainer Weiss (Chairman)
Department of Physics
Massachusetts Institute of Technology

Subcommittee for Technical Review of Gravitational Radiation Detector Projects

Richard D. Deslattes (Spokesman)
National Bureau of Standards
Washington, D.C.

David Edwards
Department of Physics
Ohio State University, Columbus

Stephen Jacobs
Optical Sciences Center
University of Arizona, Tucson

David Nygren
Lawrence Berkeley Laboratory
Berkeley, California

Arthur Rich
Department of Physics
University of Michigan

David T. Wilkinson
Department of Physics
Princeton University

Subcommittee to Review NSF-Supported Nuclear Physics Laboratories

J. A. Armstrong
Physicist, IBM
Yorktown Heights, New York

S. M. Austin
Cyclotron Laboratory
Michigan State University

D. Allan Bromley (Chairman)
Department of Physics
Yale University

Joseph Cerny
Research Chemist
Lawrence Berkeley Laboratory
Berkeley, California

Herman Feshbach
Department of Physics
Massachusetts Institute of Technology

Joseph H. Hamilton
Department of Physics and Astronomy
Vanderbilt University

Ernest M. Henley
Department of Physics
University of Washington

Gerard C. Phillips
Bonner Nuclear Laboratory
Rice University

Nicholas P. Samios
Brookhaven National Laboratory
Upton, New York

John P. Schiffer
Physics Division
Argonne National Laboratory

Dave H. Youngblood
Cyclotron Institute
Texas A&M University

Advisory Committee for Nuclear Sciences

F. Ajzenberg-Selove
David Rittenhouse Laboratory
University of Pennsylvania

R. D. Barnes
C. E. N. SACLAY
91190 Gif-sur-YVETTE, France

G. E. Brown
Department of Physics
State University of New York, Stony Brook

R. M. DeVries
Los Alamos Scientific Laboratory
Los Alamos, New Mexico

Herman Feshbach
Department of Physics
Massachusetts Institute of Technology

W. A. Fowler (Chairman)
W. K. Kellogg Radiation Laboratory
California Institute of Technology

G. T. Garvey
Argonne National Laboratory
Argonne, Illinois

W. Haeberli
Department of Physics
University of Wisconsin

I. Halpern
C.E.N. SACLAY
91190 Gif-sur-YVETTE, France

B. G. Harvey
Lawrence Berkeley Laboratory
Berkeley, California

J. R. Huizenga
Department of Physics & Chemistry
University of Rochester

E. A. Knapp
Los Alamos Scientific Laboratory
Los Alamos, New Mexico

R. E. Pollock
Indiana University Cyclotron Facility
Indiana University

D. Robson
Department of Physics
Florida State University

T. T. Sugihara
College of Science
Texas A&M University

J. D. Walecka
Department of Physics
Stanford University

Subcommittee for Facilities

G. F. Bertsch
Department of Physics
Michigan State University

R. L. Burman
Los Alamos Scientific Laboratory
Los Alamos, New Mexico

H. Feshbach (Chairman)
Department of Physics
Massachusetts Institute of Technology

B. G. Harvey
Lawrence Berkeley Laboratory
Berkeley, California

H. D. Holmgren
Department of Physics
University of Maryland, College Park

H. R. Huizenga
Department of Physics & Astronomy
University of Rochester

J. S. McCarthy
Department of Physics
University of Virginia

R. Middleton
Department of Physics
University of Pennsylvania

R. E. Pollock
Indiana University Cyclotron Facility
Indiana University

R. G. Stokstad
Oak Ridge National Laboratory
Oak Ridge, Tennessee

H. E. Wegner
Brookhaven National Laboratory
Upton, New York

Subcommittee for Manpower

F. Ajzenberg-Selove (Chairman)
David Rittenhouse Laboratory
University of Pennsylvania

G. D. O'Kelly
Oak Ridge National Laboratory
Oak Ridge, Tennessee

R. D. Parker
Department of Physics
Yale University

T. T. Sugihara
Cyclotron Institute
Texas A&M University

J. E. Walecka
Department of Physics
Stanford University

Subcommittee for Instrumentation

Robert L. Burman
Los Alamos Scientific Laboratory
Los Alamos, New Mexico

L. S. Cardman
Department of Physics
University of Illinois

David J. Clark
Lawrence Berkeley Laboratory
Berkeley, California

Ralph M. DeVries
Los Alamos Scientific Laboratory
Los Alamos, New Mexico

Harald A. Enge
Department of Physics
Massachusetts Institute of Technology

Gerald T. Garvey (Chairman)
Acting Associate Lab Director for
Physical Research
Argonne National Laboratory
Argonne, Illinois

Kazuo Gotow
Department of Physics
Virginia Polytechnic Institute and
State University

Isaac Halpern
Department of Physics
University of Washington

Willi Haeberli
Department of Physics
University of Wisconsin

David C. Hensley
Oak Ridge National Laboratory
Oak Ridge, Tennessee

Walter LeCroy
LeCroy Research Systems Corporation
Spring Valley, New York

Roy Middleton
Department of Physics
University of Pennsylvania

Veljko Radeka
Brookhaven National Laboratory
Upton, New York

Keith Rich
Stanford Linear Accelerator Center
Stanford, California

R. G. H. Robertson
Cyclotron Laboratory
Michigan State University

DIRECTORATE FOR SCIENCE EDUCATION

Advisory Committee for Science Education

Benjamin H. Alexander
President, Chicago State University
Chicago, Illinois

Ismael Almodovar
President, University of Puerto Rico
San Juan, Puerto Rico

Armand V. Alvarez
San Antonio School District
San Antonio, Texas

Mary M. Bacon
Ravenswood City School District
Hillsborough, California

Joel Bloom
Director, Science Museum and Planetarium
The Franklin Institute
Philadelphia, Pennsylvania

George Bugliarello
President, Polytechnic Institute of New York
Brooklyn, New York

John B. Davis, Jr.
President, Macalester College
Saint Paul, Minnesota

Ewaugh Fields
Dean, University College
University of the District of Columbia
Washington, D.C.

Clifford Grobstein
Science, Technology and Public Affairs
University of California, San Diego

Suzanne W. Helburn
Dean, Social Science Division
University of Colorado, Denver

Paul DeHart Hurd
School of Education
Stanford University

Philip W. Jackson
University of Chicago
Chicago, Illinois

Carol Kimmel
Rock Island, Illinois

Henry O. Pollack (Chairman)
Director, Mathematics and Statistics and Research Center
Bell Laboratories

Cheryl J. Potts
Department of Psychology
University of Nevada

Lindon E. Saline
General Electric Company
Fairfield, Connecticut

Lois Sharpe
Falls Church, Virginia

Frederick P. Thieme
Seattle, Washington

James W. Wilson
Department of Mathematics Education
University of Georgia

Advisory Committee for Minority Programs in Science Education

Don Colesto Ahshapanek
Life Science Division
Haskell American Indian Jr. College
Lawrence Kansas

Arnold T. Anderson
Middlebury, Connectucut

Ewaugh Fields (Chairperson)
Dean University College, University of the District of Columbia
Washington, D.C.

Esther A. H. Hopkins
Patent Division
Polaroid Corporation

Luis Nieves
Office of Minority Education
Educational Testing Service
Princeton, New Jersey

Antonio A. Sandoval
Department of Chemistry
University of Missouri, Kansas City

L. Shelbert Smith
National Institute of Science
Central State University

Constance Tate
Coordinator of Science
Baltimore City Public Schools
Baltimore, Maryland

Melvin W. Thompson
Council on Minorities
National Research Council
Washington, D.C.

Advisory Committee for Science and Society

Sidney Borowitz
Director, New York Academy of Science
New York, New York

Jackson Browning
Union Carbide Corporation
New York, New York

Virginia Butts
Field Enterprises, Inc.
Chicago, Illinois

Sidney deS. Callahan
Graduate School of Education
Fairfield University

Kay Davis
Fernbank Science Center
Atlanta, Georgia

Beverly B. Everett
U.S. National Commission UNESCO
New Sharon, Iowa

Loren R. Graham
Program on Science, Technology & Society
Massachusetts Institute of Technology

Clifford Grobstein (Chairman)
Science, Technology and Public Affairs
University of California, San Diego

Eugene Hess
Federation of American Societies for Experimental Biology
Bethesda, Maryland

Granger Morgan
Head, Engineering and Public Policy
Carnegie-Mellon University

Vicente Navarro
School of Hygiene and Public Health
The Johns Hopkins University

Bryon Douglas Rushing
President, Museum of Afro-American History
Boston, Massachusetts

James B. Sullivan
Cabin John, Maryland

Charles E. Tate
Booker T. Washington Foundation
Washington, D.C.

Ted Tedesco
Vice Chancellor for Administration
University of Colorado, Boulder

DIRECTORATE FOR SCIENTIFIC, TECHNOLOGICAL, AND INTERNATIONAL AFFAIRS

Advisory Committee for Information Science and Technology

Joseph Becker
Becker and Hayes, Inc.
Los Angeles, California

Elwyn R. Berlekamp
University of California, Berkeley

Joan W. Bresnan
Department of Linguistics and Philosophy
Massachusetts Institute of Technology

Ruth M. Davis
Deputy Undersecretary of Defense for Research & Advanced Technology
Washington, D.C.

Leonid Hurwicz
Department of Economics
University of Minnesota, Minneapolis

R. Duncan Luce
Department of Psychology and Social Relations
Harvard University

Ben Russak
Crane Russak
New York, New York

Paul A. Strassmann
Information Products Group
Xerox Corporation

Richard I. Tanaka
Tustin, California

Joe B. Wyatt (Chairman)
Vice President for Administration
Harvard University

Advisory Committee for International Programs

Henry Birnbaum
Office of the President
University of Southern California

James P. Blackledge
Denver, Colorado

Harrison S. Brown
The East-West Center
Honolulu, Hawaii

T. Dixon Long
Case Western Reserve University

Jamal T. Manassah
New York, New York

Norman Neureiter
Texas Instruments, Inc.
Dallas, Texas

Carol Newton
Department of Biomathematics
University of California, Los Angeles

Herman Pollack
Graduate Program in Science Technology and Public Policy
George Washington University

Harvey W. Wallender
Council of the Americas
New York, New York

Adolph Y. Wilburn
Council for International Exchange of Scholars
Washington, D.C.

Dorothy Zinberg (Chairperson)
Center for Science & International Affairs
Harvard University

Advisory Committee for Policy Research and Analysis and Science Resources Studies

Cecile deLisle Barker
OAO Corporation
Beltsville, Maryland

J. Clarence Davies
Conservation Foundation
Washington, D.C.

John H. Gibbons
Environmental Center
University of Tennessee, Knoxville

Harold Goldstein
Kramer Associates
Washington, D.C.

W. Lee Hansen
Professor of Economics
University of Wisconsin, Madison

Christopher T. Hill
Center for Policy Alternatives
Cambridge, Massachusetts

Ida R. Hoos
Space Science Technology
University of California, Berkeley

Allen V. Kneese
Department of Economics
University of New Mexico

John Kendrick
Department of Economics
George Washington University

Melvin Kranzberg (Chairman)
Callaway Professor of the History of Technology
Georgia Institute of Technology

Franklin A. Long
STS Program
Cornell University

Edwin Mansfield
Department of Economics
University of Pennsylvania

Lowell W. Steele
General Electric Company
Schenectady, New York

Raymond Tanter
Political Science Department
University of Michigan, Ann Arbor

Monte C. Throdahl
Monsanto Company
St. Louis, Missouri

Louis E. Torrence
Director of Institutional Research
University of Connecticut

Seymour Wolfbein
School of Business Administration
Temple University

Appendix B

Patents and Inventions Resulting from Activities Supported by the National Science Foundation

During fiscal year 1979, the Foundation received 110 invention disclosures and made rights determinations in 69 inventions. The determinations, made in accordance with NSF Patent Regulations, included decisions to dedicate the invention to the public through publication in 10 cases, to transfer rights to other interested Government agencies in 2 cases, and to permit retention of rights by the grantee or inventor in 57 instances. At the end of the fiscal year NSF had entered into 5 additional Institutional Patent Agreements for a total of 26. Licenses were received by the Foundation under 25 patent applications filed by grantees and contractors who had been allowed to retain principal rights in their inventions.

Number	Title	Institution
4,107,076	Catalyst System for Catalyzing the Water Gas Shift Reaction "Homogenous Catalysis of Water, Gas Shift"	University of Rochester
4,113,928	Method of Preparing Dense High Strength and Electrically Conductive Ceramic Containing Beta Alumina	University of Utah
4,115,221	Acid Ferric Sulfate Leaching of Copper Sulfate Concentrates	University of Utah
4,120,776	Separation of Bitumen from Dry Tar Sands	University of Utah
4,123,295	Mercury Chalcogenide Contact for Semiconductor Devices	California Institute of Technology
4,128,882	Packet Memory System	Massachusetts Institute of Technology
4,130,885	Packet Memory System with Hierarchial Structure	Massachusetts Institute of Technology
4,133,821	Alkylidenediquinocyclopropanes and Diarylcyclopropenes and Method for Preparation	Wisconsin Alumni Research Foundation
4,138,455	Method for Preparing Dense, Beta Alumina Ceramic Bodies by Liquid Phase Sintering	University of Utah
4,141,864	Osseous Cement Composition and Method of Using Same	University of Virginia
4,143,274	Director and Dosimeter for Neutrons and Other Radiation	Inventor: Robert E. Apfel
4,145,733	Data Processing Apparatus for Highly Parallel Execution of Stored Programs	Massachusetts Institute of Technology
4,149,240	Data Processing Apparatus for Highly Parallel Execution of Data Structure Operations	Massachusetts Institute of Technology
4,152,676	Electromagnetic Signal Processor Forming Localized Regions of Magnetic Wave Energy in Gyro-Magnetic Material	Massachusetts Institute of Technology
4,153,932	Data Processing Apparatus for Highly Parallel Execution of Stored Programs	Massachusetts Institute of Technology
4,156,814	Ionization of Thermally Labile or Nonvolatile Solids	University of Virginia
4,159,414	Method for Forming Electrically Conductive Paths	Massachusetts Institute of Technology
4,160,802	Instrument for the Automated Determination of Organic Halogens	University of Illinois Foundation
4,161,013	Electromechanochemical Device	Massachusetts Institute of Technology
4,164,444	Method for Preparing Adenosine Triphosphate	Massachusetts Institute of Technology
4,164,558	Method for Optimizing Reagents for Agglutination Reactions	Massachusetts Institute of Technology
4,167,370	Method of An Apparatus for Self-Sustaining High Vacuum in a High Voltage Environment	Massachusetts Institute of Technology

4,169,030	Light Assisted Reactions of Dinuclear Diisocyano Bridged Complexes	California Institute of Technology
4,170,319	Apparatus for Controlling Fluid Flow in A Fluid Delivery and Mixing System Utilizing Positive Displacement Devices	Massachusetts Institute of Technology
4,173,723	Photo Detector Input Circuit	Rockwell International Corporation
4,174,952	Immunoassay by Light Scattering Intensity Anisotropy Measurements	Massachusetts Institute of Technology

Appendix C

Financial Report for Fiscal Year 1979

(in Thousands of Dollars)

Research and Related Activities Appropriation Fund Availability		
Fiscal year 1979 appropriation	$827,000	
Unobligated balance brought forward	16,846	
Adjustment to prior year accounts	3,760	
Fiscal year 1979 availability		$847,606
Obligations		
Mathematical and physical sciences:		
Mathematical sciences	$22,933	
Computer research	17,585	
Physics	61,986	
Chemistry	45,626	
Materials research	63,503	
Regional instrumentation facilities	5,000	
Industry/university cooperative research	1,591	
Two-year and four-year college instrumentation	606	
Subtotal, mathematical and physical sciences		$218,830
Astronomical, atmospheric, earth, and ocean sciences:		
Astronomical sciences	$59,221	
Atmospheric sciences	59,155	
Earth sciences	36,569	
Ocean sciences	62,394	
Arctic research program	5,974	
Subtotal, astronomical, atmospheric, earth, and ocean sciences		$223,313
U.S. Antarctic program		$51,091
Biological, behavioral, and social sciences:		
Physiology, cellular, and molecular biology	$62,570	
Behavioral and neural sciences	33,073	
Environmental biology	33,953	
Social and economic science	25,386	
Subtotal, biological, behavioral, and social sciences		$154,982
Engineering and applied science:		
Electrical, computer and systems engineering	$17,044	
Chemical and process engineering	12,975	
Civil and environmental engineering	8,152	
Problem-focused research	33,938	
Mechanical science and engineering	10,759	
Industry/university cooperative research	3,781	
Intergovernmental science and public technology	8,045	
Applied research	19,895	
Subtotal, engineering and applied science		114,589

Scientific, technological, and international affairs:		
International cooperative scientific activities	$11,449	
Policy research and analysis	5,459	
Science resources studies	3,072	
Information science and technology	4,428	
NSF planning and evaluation	972	
Subtotal, scientific, technological, and international affairs		$25,380
Program development and management		$54,766
Subtotal, obligations		$842,951
Unobligated balance carried forward		$3,341
Unobligated balance lapsing		$1,314
Total, fiscal year 1979 availability for research and related activities		$847,606

Science Education Activities Appropriation Fund Availability

Fiscal year 1979 appropriation	$80,000	
Unobligated balance brought forward	9	
Fiscal year 1979 availability		$80,009

Obligations

Science education activities:		
Scientific personnel improvement	$33,072	
Science education resources improvement	28,606	
Science education development and research	12,014	
Science and society	6,287	
Subtotal, obligations		$79,979
Unobligated balance lapsing		$30
Total, fiscal year 1979 availability for science education activities		$80,009

Special Foreign Currency Appropriation Fund Availability

Fiscal year 1979 appropriation	$4,000	
Unobligated balance brought forward	5	
Fiscal year 1979 availability		$4,005

Obligations

Special foreign currency program:		
Research and related activities	$3,836	
Science information	165	
Subtotal, obligations		$4,001
Unobligated balance carried forward		4
Total, fiscal year 1979 availability for special foreign currency program		$4,005

Trust Fund

Fund Availability		
Unobligated balance brought forward	$4,336	
Receipts from non-Federal sources	3,133	
Adjustment to prior year accounts	69	
Fiscal year 1979 availability		$7,538
Obligations		
Astronomical, atmospheric, earth, and ocean sciences activity (ocean sediment coring program)	$5,081	
Gifts and donations	9	
Subtotal, obligations		$5,090
Unobligated balance carried forward		$2,448
Total, fiscal year 1979 availability for trust fund		$7,538

SOURCES: Fiscal year 1981 Supplementary Budget Schedules, Fiscal Year 1981 Budget to Congress, and NSF accounting records.

Appendix D

National Research Centers Contractors

Associated Universities, Inc. (AUI)
Gerald F. Tape, President

National Radio Astronomy Observatory
Morton S. Roberts, Director

AUI Member Universities:
Columbia University
Cornell University
Harvard University
The Johns Hopkins University
Massachusetts Institute of Technology
University of Pennsylvania
Princeton University
University of Rochester
Yale University

Association of Universities for Research in Astronomy, Inc., (AURA)
John M. Teem, President

Cerro Tololo Inter-American Observatory
Victor M. Blanco, Director
Kitt Peak National Observatory
Geoffrey Burbidge, Director
Sacramento Peak Observatory
Jack B. Zirker, Director

AURA Member Universities:
University of Arizona
California Institute of Technology
University of California
University of Chicago
University of Colorado
Harvard University
University of Hawaii
Indiana University
University of Michigan
Ohio State University
Princeton University
University of Texas at Austin
University of Wisconsin
Yale University

Cornell University
W. Donald Cooke, Vice President for Research

National Astronomy and Ionosphere Center
Frank D. Drake, Director, Ithaca, N.Y.
Harold D. Craft, Director, Observatory
Operations, Arecibo, P.R.

University Corporation for Atmospheric Research (UCAR)
Francis P. Bretherton, President

National Center for Atmospheric Research
Francis P. Bretherton, Director

UCAR Member Universities:
University of Alaska
University of Arizona
California Institute of Technology
University of California
The Catholic University of America
University of Chicago
Colorado State University
University of Colorado
Cornell University
University of Denver
Drexel University
Florida State University
Harvard University
University of Hawaii
Iowa State University
The Johns Hopkins University
University of Illinois at Urbana-Champaign
University of Maryland
Massachusetts Institute of Technology
McGill University
University of Miami
University of Michigan
University of Minnesota
University of Missouri
University of Nebraska
University of Nevada
New Mexico Institute of Mining and Technology
New York University
State University of New York at Albany
University of North Carolina
Ohio State University
University of Oklahoma
Oregon State University
Pennsylvania State University
Purdue University
The Rice University
Saint Louis University
Stanford University
Texas A&M University
University of Texas
University of Toronto
Utah State University
University of Utah
University of Virginia
University of Washington
University of Wisconsin (Madison)
University of Wisconsin (Milwaukee)
University of Wyoming
Woods Hole Oceanographic Institution

U.S. GOVERNMENT PRINTING OFFICE : 1980 O - 318-931